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June 26, 1986

Mr. C. Hughes
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Cleveland, Ohio 44135

Dear Chris:

Enclosed are three copies each of the following reports:

(1) Cornell, C.C., "Experimental and Theoretical Study of Propeller Spinner/Shank Interference, Master of Science Thesis, Aerospace Engineering Department, Texas A&M University, May 1986.

(2) Korkan, K.D., Camba, J., and Morris, P.M., "Aerodynamic Data Banks for Clark Y, NACA 4-Digit, and NACA 16-Series Airfoil Families," Aerospace Engineering Department, Texas A&M University, January 1986.

These constitute the final reports under NASA Lewis Research Center Grant NAS 3-272 (TAMU RF4669).

As a final comment, Mr. Carl Cornell has presented his thesis at the Student Paper Competition in Ft. Worth in April and won first ... Graduate Division. He will therefore enter the national ... present his thesis at the AIAA Aerospace Sciences Meeting ... 1987-expenses paid by AIAA.

We are attempting to get to Cleveland in ... time. Also, I have shipped two copies of ... Scientific and Technical Information Fa... you have any ... hesitate to contact me.

AERODYNAMIC DATA BANKS FOR CLARK-Y, NACA 4-DIGIT, AND NACA 16-SERIES AIRFOIL FAMILIES.

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LEWIS RESEARCH CENTER

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This document represents the effort expended under NASA Lewis Research Center Grant NAS 3-272 to Texas A&M University under the direction of Mr. C. Hughes of the Propeller Aerodynamics Section. This work was a continuing effort which spanned the time period from 1981 to 1985. The three principal authors have been indicated on this report, however it is to be noted that other students at the Aeronautical and Astronautical Laboratory of The Ohio State University and of the Aerospace Engineering Department of Texas A&M University have also been involved in both the Computer Programming and documentation of these Aerodynamic databanks. The authors wish to acknowledge these students for their participation, and to NASA Lewis Research center for providing the funding to complete this project.

FOREWORD

With the renewed interest in propellers as means of obtaining thrust and fuel efficiency in addition to the increased utilization of the computer, a significant amount of progress has been made in the development of theoretical models to predict the performance of propeller systems. Inherent in the majority of the theoretical performance models to date is the need for airfoil data banks which provide lift, drag, and moment coefficient values as a function of Mach number, angle-of-attack, maximum thickness to chord ratio, and Reynolds number. Realizing the need for such data, a study was initiated to provide airfoil data banks for three commonly used airfoil families in propeller design and analysis. The families chosen consisted of the Clark-Y, NACA 16 series, and NACA 4 digit series airfoils. The following Chapters briefly describe the various components of each computer code, the source of the data used to create the airfoil data bank, the limitations of each data bank, program listing, and a sample case with its associated input-output. Each airfoil data bank computer code has been written to be used on the Amdahl Computer system, which is IBM compatible and uses Fortran language.

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I. CLARK-Y AIRFOIL DATA BANK

1. Introduction

The Clark-Y airfoil data bank has been created to calculate the lift, drag, and moment coefficient for a specified Clark-Y airfoil at a given angle-of-attack, Mach number, and Reynolds number. Since the Clark-Y airfoil family was created before the advent of the present NACA airfoil families with its attendent superposition of camberline and thickness distribution[1], there is an interrelationship between the design lift coefficient (C_{LD}) and maximum thickness to chord ratio (t/c)max. That is, the airfoil is defined by either a value of (t/c)max or C_{LD}, and the unknown parameter is calculated based upon a previously given correlation.[2] In addition, the data bank calculates the airfoil section coordinates and moments of inertia if desired. The methods used to calculate various airfoil parameters have been obtained from tabular and graphical data from Haines and Monagwan[3], and MacDougall[4]. Moment data were obtained and placed into the airfoil data bank using the airfoil analysis computer program by Smetana, et. al.[5], by conducting a numerical analysis of representative Clark-Y airfoil sections. Comparisons were also conducted with the Smetana et.al.[5] airfoil analysis computer code and the Clark-Y airfoil data bank for 69 cases. C_l, C_d, and C_m were compared for conditions ranging in Mach numbers from 0.1 to 0.5, angle-of-attack (α) from -1.7 to 5.3^o, and (t/c)max 0.05 to 0.30. The % differences between the Clark-Y airfoil data bank and the

Smetana airfoil analysis computer code ranged from -15% to 10% as shown in Table I.

The computer code is divided into various subroutines in order to simplify the computations, which contain the bulk of the tabular data. A description of the subroutines ATMCON, CLTMAX, CYCOOR, CLCD, and CMFF is provided in the following Sections.

2. Input

The parameters used as input to the program have been summarized in Table II. These parameters include the Mach number(s), angle(s)-of-attack referenced from the longest chord line, altitude, chord length in feet, maximum thickness-to-chord ratio, and the number of Mach numbers and angles-of-attack to be evaluated. Parameters indicating whether the airfoil coordinates, moments of inertia, and moment coefficients are to be calculated and presented in the program output are also to be designated, as well as the design lift coefficient and/or (t/c)max.

3. Main Program

The main program works as an operating system which routes input data to the various subroutines which are described in the following Sections. The output from the subroutines is passed back to the main program and output. It should be noted that all interpolation in the computer code is done by the Lagrangian method.

4. Subroutine ATMCON

ATMCON calculates the temperature, pressure, speed of sound, density, and viscosity for a specified altitude using the empirical equations of Minzer, et.al.[6] as given by Anderson[7]. These equations have been curve fitted from the available data of the ARDC 1959 standard atmosphere,[7] and divide the atmosphere into two regions, ie., from sea level to 11,000 meters, and 11,000 to 25,000 meters. These equations are given as:

<u>Sea level to 11,000 meters</u>.

$$Temp = 288.16 - 0.0065\ h \tag{I-1}$$

$$P = (101325)/(1/Temp/288.16)^{-5.2457} \tag{I-2}$$

<u>11,000 meters to 25,000 meters</u>.

$$Temp = 216.66 \tag{I-3}$$

$$P = (22{,}703.59)\exp(0.0001547(h-11{,}000) \tag{I-4}$$

where h is in meters, Temperature is in ^{o}K, and pressure, P is in N/m^2. The values of P and Temp are converted by:

$$Temp = (Temp - 273.15)\ 9/5 + 491.67 \tag{I-5}$$

$$P = 2116.2\ P/101325 \tag{I-6}$$

where Temp and P are now in units of ^{o}R and lbs/ft^2. Values of density, viscosity, and speed of sound are then calculated by:

$$\text{Density} = (\text{Pressure})/(1718)(\text{Temp}) \qquad \text{I-7}$$

$$\text{Viscosity} = 3.5 \times 10^{-7}\ (\text{Temp}/492)^{1.5}\ (690/(\text{Temp}+198)) \qquad \text{I-8}$$

$$\text{Speed of Sound} = \sqrt{((403.2)\ (\text{Temp}))/0.3047} \qquad \text{I-9}$$

where density is in lb-ft^2/sec^4, viscosity in lb-sec/ft^2, and speed of sound in ft/sec.

5. Subroutine CLTMAX

CLTMAX calculates the design lift coefficient as a function of (t/c)max, or (t/c)max as a function of design lift coefficient depending on which is the unknown parameter. Using the data tabulated by Pinkerton and Greenberg[2], an empirical relationship has been determined in which C_{LD} can be found by specifying the (t/c)max, i.e.,

$$C_{LD} = \frac{-0.1688 + \sqrt{(0.0285 + 0.4964\ (t/c)\max)}}{0.2482} \qquad \text{I-10}$$

If the desired lift coefficient NCLD is known, then the following equations are used to determine the corresponding (t/c)max, i.e.,

$$\text{NTMAX} = 0.1241\ \text{NCLD}^2 + 0.1688\ \text{NCLD} \qquad \text{I-11}$$

The value of the low speed lift-curve slope, a_o, is also determined for a given (t/c)max by interpolation of data shown in Figure 1-Table III and stored in FUNCTION AOIOF. The correlations to the low speed lift-curve slope for thickness is given by the equation:

$$a_o = (0.0196(1-(t/c)max))/\sqrt{1-(t/c)max^2} \qquad \text{I-12}$$

With the values of a_o and CLD, the zero-lift angle-of-attack can be calculated using the expression:

$$\alpha_{L=0} = C_{LD}/(-a_o) \qquad \text{I-13}$$

6. Subroutine CYCOOR

CYCOOR gives the dimensions and section properties for a Clark-Y airfoil for a specified thickness and chord. This subroutine also calculates the moment of inertia for the major and minor axes if required, by the following equations:

$$\text{Major Moment of Inertia} = 0.0418\ (\text{Chord})^4\ ((t/c)max) \qquad \text{I-14}$$

$$\text{Minor Moment of Inertia} = 0.0454\ (\text{Chord})^4\ ((t/c)max)^3 \qquad \text{I-15}$$

The coordinates are scaled to the required thickness to chord ratio by utilizing the data listed in Tables IV and V. The airfoil coordinates are non-dimensionalized with respect to the chord, where the upper and lower chordwise X coordinate locations are identical resulting in one column in the output data format. The airfoil coordinates are also supplied in the output as the actual coordinates as specified by the chord.

7. Subroutine CLCD

CLCD calculates C_l, C_d, C_l/C_d and critical Mach numbers for lift and drag divergence. The subroutine consists of data tables from References 2 and 3 from which desired values are obtained by interpolation using the input parameters. C_{lo} is the low speed incompressible lift coefficient and is defined by $C_{lo} = f(a_o, \alpha_o)$, where α_o is the angle-of-attack relative to the zero lift line, and a_o is the low speed lift-curve slope. If the airfoil section (t/c)max is greater than 0.16%, then a_o is interpolated from Table VI. For (t/c)max less than or equal to 0.16%, a critical Mach number is determined, where the critical Mach number has been taken as the point at which C_L departs from the Prandtl-Glauert relation as given by:

$$C_l = C_{lo}/\sqrt{1-M^2} = a_o/\sqrt{1-M^2}\,\alpha_o \qquad \text{I-16}$$

where C_L is the lift coefficient for M less than the critical Mach number (M_L). The critical Mach number for lift, M_L, is found from Table VII. As noted, if M is less than M_L, then the Prandtl-Glauert relation accounts for compressibility effects. If the Mach number is greater than the critical value, an incremental lift coefficient, C_{ls}, is added to account for the lift coefficient divergence from the low speed value. C_{ls} is found in Table VIII as a function of $(M-M_L)$. In either case ($M > M_L$ or $M < M_L$), the lift curve slope is found by FUNCTION AOF which uses the data contained in Table XI.

As in the case of C_l, a critical Mach number M_D is defined, where M_D is determined by Tables X and XI as a function of α_o and (t/c)max. If the Mach number is below the critical value:

$$C_{do} = B_o(\alpha)\ C_o(t/c)max \qquad \text{I-17}$$

where C_{do} is the low speed drag coefficient for $M < M_D$. $B_o(\alpha_o)$ is a function dependent only on angle-of-attack and is found in Table XII, whereas $C_o(t/c)$ is found in Table XIII and is a function only of (t/c)max. When M becomes larger than M_D, the drag coefficient departs from the low speed relationship and is given by,

$$C_d = C_{do} + C_{ds} \qquad \text{I-18}$$

where C_{ds} is the incremental drag coefficient due to compressibility and is found from Table XIV as a function of $(M-M_D)$. If the airfoil section thickness is less than or equal to 9%, C_{ds} is taken as zero. For airfoil section thicknesses greater than 9% and α_o greater than 5^o--or for airfoil sections thicker than 16%--C_{ds} can no longer be treated as independent of all variables except $(M-M_D)$ as given in Table XIV. In these case, plots of C_d as a function of M are used directly, and are used in tabular form in subroutine FUNCTION CD9F - CD35F as given in Figures 2 through 16.

8. Subroutine Function CMFF

FUNCTION CMFF calculates the moment coefficient about the leading edge or quarter chord location of the airfoil. The variation of the moment coefficients with lift coefficient was first determined for a representative number of Clark-Y airfoil (t/c)max values using the airfoil analysis code of Smetana, et.al.[5]. A linear relationship was determined between the lift and moment coefficient, and the variation of the slope and intercept with varying (t/c)max was determined. Quadratic equations were then used to fit the resulting curves, and substituted into the linear relationships to obtain the final equations, e.g., the equation for the moment coefficient about the leading edge, expressed as:

$$CM_{le} = (t/c)max^2(-0.3065\ C_l + 0.875) - (t/c)max\ (0.1514\ C_l + 0.705) - 0.23993C_l + 6.25 \times 10^{-5} \qquad \text{I-19}$$

and the moment coefficient about the quarter chord, given by:

$$CM_{qc} = (-0.44\ C_l + 1.15)\ (t/c)max^2 - (0.0993\ C_l + 0.785) + 0.0036\ C_l - 0.00638 \qquad \text{I-20}$$

Compressibility effects are accounted for by the Prandtl-Glauert factor by the relationship:

$$CM_{le} = (CM_{le})_o / \sqrt{1-M^2} \qquad \text{I-21}$$

$$CM_{c/4} = (CM_{c/4})_o / \sqrt{1-M^2} \qquad \text{I-22}$$

where $(CM_{le})o$ and $(CM_{c/4})_o$ are the incompressible moment coefficients about the airfoil leading edge and quarter chord, respectively.

9. Limitations

The maximum lift coefficient and corresponding angle-of-attack cannot be determined since the program assumes a constant value for the lift-curve slope, and does not recognize stall. Also, the following limits are suggested for the input parameters:

$0.06 < (t/c)_{max} < 0.22$ $\qquad$ $0.33 < C_{LD} < 0.90$

$-1.50^{o} < \alpha < 11^{o}$ $\qquad$ $0.01 < M < 0.80$

These limits can be exceeded slightly and the computer program extrapolation will still predict accurate aerodynamic values. However, when the specified limits have been exceeded by a significant amount, flags are contained in the printed output to alert the User that the airfoil data bank tabular data has been exceeded. For example, these take the form of:

T/C=0.300000 IS GREATER THAN (T/C)MAX= 0.220000 OF SUBROUTINE CLTMAX

MACH NO.=0.950000 IS GREATER THAN MACH NO.(MAX)=0.800000 OF FUNCTION THKSLP

ALPHAO=ALPHA-ALPHLO=27.712020 IS GREATER THAN ALPHADMAX=11.000000 OF FUNCTIN CDFF

ALPHAD=ALPHA-ALPHLO=27.712020 IS GREATER THAN ALPHAOMAX=11.000000 OF FUNCTION CDFF

T/C=0.300000 IS GREATER THAN (T/C)=0.250000 OF FUNCTION CMFF

10. Program Listing

The program has been written in Fortran, and a listing is provided in Appendix I. The computer code listing contains numerous comment statements, which will assist the User in its utilization and application.

11. Output

The numerical output consists of the lift and drag coefficient at a specified angle-of-attack and Mach numbers, in addition to the design lift coefficient and (t/c)max. The User may choose whether the (X,Y) airfoil coordinates, moments of inertia, and moment coefficients are to be calculated and included in the computer output through proper input parameter selection as discussed earlier. Two cases, contained in Appendix II, indicate a sample input and output of the Clark-Y airfoil data bank computer code.

The first case shown in Appendix II, is for Mach numbers of 0.0, 0.1, 0.2 and 0.4 and a range of α's from -1^{o} to 5^{o}. The (t/c)max has been specified at 11.70 resulting in a CLD of .505381 The parameters have been set to provide the airfoil coordinates, moment coefficient about the quarter chord, and the moments of inertia. The second case corresponds to airfoil parameters and a flight condition which exceeds the suggested range of input values, and the case has been run to exhibit all flags.

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3. Haines, A.B., and Monagwan, R.J., "High Speed Lift and Drag Data for Propeller Performance Calculations", Royal Aircraft Establishment, Reports and Memorandum No. 2036, 1945.

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5. Smetana, F.O., Summey, D.C., Smith, N.S., and Carden, R.K., "Light Aircraft Lift, Drag, and Moment Prediction--A Review and Analysis", NASA CR-2523, May 1975.

6. Minzner, R.A., Champoin, K.S.W., and Pond, H.L., "The ARDC Model Atmosphere", Air Force Cambridge Research Center Report No. TR-59-267, 1959.

7. Anderson, Jr., J.D., Introduction to Flight, McGraw-Hill Book Company, 1978.

Table I. Comparison Cases for Clark-Y Airfoil Data Bank.

t/c	Mach No.	α	Calculated Values C_l	Calculated Values C_d	Clark-Y C_l	Clark-Y C_d	Δ% C_l	Δ% C_d
0.05	0.1	-1.7	0.002725	0.009251	0.061097	0.00767	-242.1	17.1
	0.1	5.3	0.694748	0.011917	0.794875	0.00962	-14.4	23.9
	0.2	-1.7	0.072763	0.007495	0.062044	0.00767	14.7	-2.3
	0.2	5.3	0.786452	0.011221	0.807199	0.00962	- 2.6	14.3
	0.3	-1.7	0.073496	0.006732	0.063726	0.00767	13.3	-13.93
	0.3	5.3	0.844358	0.010975	0.829078	0.00962	1.84	14.09
	0.4	-1.7	0.073592	0.006524	0.066328	0.007670	9.9	-17.6
	0.4	5.3	0.878836	0.010911	0.862932	0.00962	1.84	13.42
0.10	0.1	-1.7	0.278982	0.008901	0.279050	0.008683	-0.02	2.51
	0.1	5.3	0.976437	0.014454	0.976244	0.013603	0.02	6.26
0.15	0.1	-1.7	0.466541	0.011643	0.48055	0.010474	-2.92	11.16
	0.1	5.3	1.280765	0.019659	1.181261	0.017041	7.8	13.3
	0.2	-1.7	0.473774	0.009326	0.488001	0.010474	-2.92	-10.96
	0.2	5.3	1.147843	0.017278	1.199576	0.017041	-4.31	1.39
	0.3	-1.7	0.583900	0.008770	0.501228	0.010474	14.2	-19.4
	0.3	5.3	1.178956	0.016847	1.232091	0.017041	-4.31	-1.14
	0.4	-1.7	0.618247	0.008767	0.521694	0.010474	15.6	-19.5
	0.4	5.3	1.227096	0.018190	1.282401	0.017041	-4.31	6.74
0.20	0.2	-1.7	0.626981	0.012140	0.653970	0.015293	-4.05	-20.62
	0.2	1.0	0.873751	0.01213	0.91321	0.019054	-4.32	-36.34
	0.2	3.0	1.056545	0.015714	1.105609	0.021678	-4.44	-27.51
	0.3	1.0	0.894435	0.011339	0.921633	0.019054	-2.63	-40.49
	0.3	3.0	1.085182	0.015443	1.115808	0.021678	-2.74	-28.76
	0.4	1.0	0.93408	0.012828	0.921633	0.019054	1.35	-32.68
	0.4	3.0	1.129494	0.015624	1.115808	0.021678	1.23	-27.93
	0.5	1.0	0.988537	0.014593	0.930669	0.026556	6.22	-45.05
	0.5	3.0	1.195344	0.016856	1.126747	0.038693	6.09	-56.44
	0.2	5.3	1.266757	0.023754	1.326869	0.024840	-4.53	-4.37
0.25	0.1	-1.7	0.725286	0.021237	0.779343	0.019192	-6.94	10.66
	0.1	5.3	1.797551	0.034872	1.396043	0.025846	22.3	25.9
	0.2	-1.7	0.736531	0.017911	0.779343	0.019192	-5.49	-6.67
	0.2	5.3	1.869015	0.030952	1.396143	0.025846	25.3	16.5
	0.3	-1.7	0.756495	0.017347	0.775975	0.019192	-2.51	-9.61
	0.3	5.3	1.962380	0.031499	1.390010	0.025846	29.2	17.9
	0.4	-1.7	0.787385	0.019823	0.775975	0.019192	1.47	3.29
	0.4	5.3	2.087362	0.034636	1.390010	0.025846	33.4	25.4
0.30	0.1	1.0	1.066446	0.026865	1.011948	0.023712	5.39	13.3
	0.1	3.0	1.229262	0.028877	1.159548	0.025712	6.01	12.31
	0.2	1.0	1.082981	0.022968	1.011948	0.023712	7.02	-3.14
	0.2	3.0	1.248321	0.025095	1.159548	0.025712	7.76	-2.40

Table I. (cont.).

t/c	Mach No.	α	NCState Values CM_{le}	NCState Values $CM_{c/4}$	Clark-Y Values CM_{le}	Clark-Y Values $CM_{c/4}$	Δ% CM_{le}	Δ% $CM_{c/4}$
0.05	0.1	-1.7	-0.037527	-0.036915	-0.048411	-0.030297	29.0	17.9
	0.1	5.3	-0.213142	-0.039922	-0.231501	-0.032115	8.6	19.6
	0.2	-1.7	-0.055661	-0.037534	-0.049401	-0.030770	11.2	18.0
	0.2	5.3	-0.237509	-0.041478	-0.238213	-0.032644	0.3	21.3
	0.3	-1.7	-0.056608	-0.038292	-0.051178	-0.031608	9.6	17.5
	0.3	5.3	-0.245588	-0.042193	-0.250364	-0.033586	1.4	20.4
	0.4	-1.7	-0.057733	-0.039392	-0.053973	-0.032906	6.5	16.5
	0.4	5.3	-0.256672	-0.043104	-0.269758	-0.035048	5.1	18.7
0.15	0.1	-1.7	-0.239095	-0.107546	-0.216611	-0.096162	9.4	10.6
	0.1	5.3	-0.442770	-0.123494	-0.406430	-0.111089	8.2	10.0
	0.2	-1.7	-0.248945	-0.111580	-0.222019	-0.097814	10.8	12.3
	0.2	5.3	-0.460841	-0.128497	-0.417770	-0.113207	9.3	11.9
	0.3	-1.7	-0.264226	-0.118381	-0.231775	-0.100760	12.3	14.9
	0.3	5.3	-0.479964	-0.132887	-0.438280	-0.116998	8.7	12.0
	0.4	-1.7	-0.278711	-0.124283	-0.247258	-0.105347	11.3	15.2
	0.4	5.3	-0.504056	-0.138172	-0.470972	-0.122939	6.6	11.0
0.25	0.1	-1.7	-0.437634	-0.182717	-0.354693	-0.156754	19.0	14.2
	0.1	5.3	-0.666768	-0.218497	-0.538736	-0.186954	19.2	14.4
	0.2	-1.7	-0.459411	-0.191142	-0.360193	-0.159185	21.6	16.7
	0.2	5.3	-0.690927	-0.224956	-0.547089	-0.189853	20.8	15.6
	0.3	-1.7	-0.481981	-0.200247	-0.368907	-0.163327	23.5	18.4
	0.3	5.3	-0.723665	-0.723665	-0.234441	-0.560040	22.6	17.0
	0.4	-1.7	-0.501372	-0.208132	-0.383971	-0.169996	23.4	18.3
	0.4	5.3	-0.768756	-0.248347	-0.582908	-0.202641	24.2	18.4

Table II. Clark-Y Airfoil Databank Input Parameters.

HM	Mach Number (Free-Stream)
ALPHA	Angle(s)-of-Attack
ALTITUDE	Geometric Attitude in Feet
CHORD	Longest Chord Length (Feet)
NUMACH	Numbers of Mach Numbers
NUALP	Number of Angle-of-Attack
NCL	Lift coefficient Parameter = 0 if C_l is not desired = 1 if C_l is desired
NCD	Drag Coefficient Parameter = 0 if C_d is not desired = 1 if C_d is desired
NCLD	Design Lift Coefficient = 0.0 if value is unknown
T	Maximum Thickness-to-Chord Ratio = 0.01 if Value is Unknown
L	Section Coordinates Parameter = 0 if airfoil coordinates and moments of inertia are not desired = 1 if airfoil coordinates and moments of inertia are desired
M	Moment Coefficient Parameter = 0 if CM is not desired = 1 for CM_{le} = 2 for $CM_{c/4}$

Table III. Variation of Lift Curve Slope with Thickness.

t/c	ao	α	C_{1d}
0.0	0.1096	0.0	0.0
0.06	0.103210	-2.9	0.2993
0.08	0.101156	-3.6	0.36416
0.10	0.099137	-4.5	0.446116
0.14	0.095193	-6.2	0.590197
0.18	0.091364	-7.6	0.694366
0.22	0.087635	-9.3	0.815006

Table IV. Clark-Y Airfoil Dimensions (t/c = .20).

X-Coordinates	Y-Coordinates(upper)	Y-Coordinates(lower)
0.00	0.0588	0.0588
0.0025	0.0671	0.0505
0.025	0.1100	0.0262
0.050	0.1330	0.1640
0.100	0.1616	0.0076
0.200	0.1918	0.0013
0.300	0.2000	0.0000
0.400	0.1970	0.0000
0.500	0.1860	0.0000
0.600	0.1660	0.0000
0.700	0.1370	0.0000
0.800	0.1046	0.0000
0.900	0.0676	0.0000
1.000	0.0226	0.0000

Table V. Clark-Y Airfoil Dimensions (t/c = .35).

X-Coordinates	Y-Coordinates(upper)	Y-Coordinates(lower)
0.000	0.1290	0.1029
0.0025	0.1112	0.0946
0.025	0.1925	0.0459
0.050	0.2328	0.0288
0.100	0.2828	0.0133
0.200	0.3357	0.0235
0.300	0.3500	0.0000
0.400	0.3447	0.0000
0.500	0.3255	0.0000
0.600	0.2905	0.0000
0.700	0.2393	0.0000
0.800	0.1831	0.0000
0.900	0.1183	0.0000
1.000	0.0396	0.0000

Table VI. Values of a x (solidity).

M	a x (solidity) + 1/ $\frac{\delta C_1}{\delta a_o}$								
	t/c = 15%	17%	19%	21%	23%	25%	30%	35%	40%
0.4	9.2	9.6	10.1	10.5	10.9	11.4	13.6	19.2	30.0
0.45	8.95	9.4	10.0						
0.50	8.7	9.2	9.9						
0.55	8.4	8.95	9.8						
0.60	8.0	8.8							
0.65	7.9								
0.70									
0.75									
0.80									

Table VII. Values of M_L.

t/c per cent	< 3°	3.5°	4°	4.5°	5°	5.5°	6°	6.5°	7	7.5°	8°	8.5°	9°	9.5°	10°	10.5°	11°
4	0.879	0.874	0.867	0.859	0.848	0.836	0.823	0.808	0.794	0.781	0.768	–	–	–	–	–	–
4.5	0.858	0.852	0.846	0.838	0.828	0.817	0.805	0.792	0.778	0.765	0.751	–	–	–	–	–	–
5	0.835	0.830	0.825	0.817	0.807	0.797	0.787	0.775	0.762	0.748	0.734	–	–	–	–	–	–
5.5	0.810	0.807	0.804	0.798	0.789	0.780	0.771	0.760	0.745	0.731	0.717	–	–	–	–	–	–
6	0.790	0.789	0.786	0.781	0.774	0.765	0.755	0.744	0.730	0.716	0.701	0.685	0.667	–	–	–	–
6.5	0.775	0.775	0.773	0.768	0.761	0.752	0.742	0.731	0.717	0.702	0.687	0.670	0.652	–	–	–	–
7	0.762	0.762	0.760	0.756	0.749	0.740	0.730	0.718	0.704	0.689	0.673	0.656	0.638	0.620	0.601	0.582	0.564
7.5	0.751	0.751	0.749	0.745	0.738	0.729	0.719	0.706	0.691	0.676	0.661	0.644	0.626	0.608	0.589	0.570	0.552
8	0.742	0.742	0.740	0.735	0.728	0.719	0.707	0.695	0.679	0.663	0.648	0.631	0.613	0.595	0.576	0.558	0.541
8.5	0.732	0.732	0.730	0.725	0.718	0.709	0.697	0.684	0.667	0.651	0.635	0.618	0.601	0.583	0.564	0.547	0.531
9	0.723	0.723	0.721	0.716	0.709	0.699	0.687	0.674	0.657	0.640	0.622	0.606	0.588	0.570	0.552	0.536	0.521
9.5	0.713	0.713	0.711	0.707	0.699	0.689	0.675	0.663	0.646	0.628	0.611	0.593	0.575	0.558	0.541	0.526	0.511
10	0.704	0.704	0.702	0.698	0.689	0.679	0.666	0.652	0.635	0.617	0.599	0.580	0.563	0.546	0.530	0.516	0.502
10.5	0.695	0.695	0.694	0.689	0.680	0.669	0.656	0.641	0.623	0.605	0.587	0.568	0.551	0.535	0.519	0.505	0.493
11	0.686	0.686	0.685	0.680	0.671	0.660	0.646	0.629	0.611	0.593	0.575	0.556	0.539	0.524	0.509	0.496	0.485
11.5	0.677	0.677	0.676	0.671	0.663	0.650	0.635	0.618	0.600	0.582	0.563	0.545	0.528	0.513	0.499	0.487	0.477
12	0.669	0.669	0.668	0.663	0.654	0.641	0.625	0.607	0.588	0.570	0.551	0.534	0.518	0.503	0.490	0.479	0.470
12.5	0.660	0.660	0.658	0.654	0.646	0.631	0.614	0.595	0.577	0.558	0.539	0.523	0.508	0.494	0.481	0.471	0.463
13	0.651	0.651	0.649	0.645	0.637	0.621	0.603	0.581	0.565	0.546	0.528	0.513	0.498	0.484	0.473	0.463	0.456
13.5	0.643	0.643	0.641	0.637	0.627	0.611	0.591	0.572	0.553	0.533	0.517	0.503	0.489	0.475	0.465	0.457	0.450
14	0.635	0.635	0.633	0.628	0.618	0.600	0.579	0.560	0.541	0.523	0.507	0.493	0.479	0.467	0.458	0.450	0.445
14.5	0.627	0.627	0.625	0.620	0.612	0.589	0.567	0.548	0.530	0.513	0.498	0.484	0.471	0.460	0.451	0.444	0.439
15	0.618	0.618	0.616	0.611	0.602	0.578	0.555	0.536	0.518	0.502	0.489	0.474	0.462	0.453	0.445	0.439	0.433
15.5	0.610	0.610	0.608	0.603	0.593	0.568	0.543	0.524	0.507	0.492	0.479	0.466	0.454	0.446	0.438	0.432	0.427
16	0.603	0.603	0.601	0.596	0.585	0.559	0.532	0.513	0.496	0.483	0.470	0.457	0.446	0.439	0.432	0.426	0.422

Table VIII. Values of C_{1s}.

$(M-M_L)$	C_{1s}
0.01	0.010
0.02	0.017
0.03	0.022
0.04	0.025
0.05	0.026
0.06	0.025
0.07	0.021
0.08	0.015
0.09	0.007
0.10	-0.002
0.11	-0.014
0.12	-0.027
0.13	-0.040
0.14	-0.054
0.15	-0.070
0.16	-0.086
0.17	-0.102
0.18	-0.119
0.19	-0.138
0.20	-0.157
0.21	-0.175
0.22	-0.193
0.23	-0.212
0.24	-0.231
0.25	-0.250
0.26	-0.270
0.27	-0.289
0.28	-0.307
0.29	-0.325
0.30	-0.344
0.31	-0.363
0.32	-0.381
0.33	-0.400
0.34	-0.417
0.35	-0.432
0.36	-0.446
0.37	-0.459
0.38	-0.470
0.39	-0.478
0.40	-0.485

Table IX. Values of a_o (slope of low-speed curve).

t/c per cent.	a_o	t/c per cent.	a_o
10	0.0999	21	0.0950
11	0.0999	22	0.0936
12	0.0999	23	0.0920
13	0.0999	24	0.0902
14	0.0998	25	0.0881
15	0.0996	26	0.0858
16	0.0992	27	0.0832
17	0.0987	28	0.0804
18	0.0980	29	0.0773
19	0.0972	30	0.0738
20	0.0962		

Table X. Values of M_D.

	α_o										
t/c%	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
4.5	0.820	0.810	0.787	0.762	0.735	0.707	0.680	0.651	0.621	0.593	0.565
5	0.811	0.817	0.805	0.785	0.761	0.735	0.707	0.680	0.650	0.620	0.591
6	0.782	0.800	0.808	0.806	0.796	0.779	0.756	0.731	0.702	0.671	0.641
7	0.750	0.774	0.790	0.799	0.800	0.795	0.781	0.761	0.737	0.708	0.679
8	0.728	0.750	0.768	0.776	0.774	0.766	0.752	0.733	0.713	0.690	0.663
9	0.709	0.728	0.746	0.755	0.752	0.741	0.724	0.705	0.684	0.672	0.641
10	0.691	0.709	0.725	0.735	0.732	0.716	0.697	0.678	0.660	0.642	0.625
11	0.674	0.690	0.705	0.715	0.715	0.699	0.681	0.662	0.644	0.626	0.610
12	0.658	0.672	0.685	0.696	0.698	0.684	0.667	0.648	0.630	0.612	0.597
13	0.643	0.656	0.667	0.678	0.682	0.671	0.657	0.639	0.620	0.602	0.587
14	0.629	0.640	0.651	0.661	0.667	0.662	0.650	0.632	0.611	0.593	0.580
15	0.614	0.625	0.637	0.647	0.655	0.654	0.643	0.626	0.605	0.586	0.574
16	0.600	0.613	0.625	0.637	0.646	0.648	0.637	0.621	0.600	0.580	0.570

Table XI. Values of M_D.

	α_0								
t/c%	-1.5	-1.0	-0.5	0	5.0	5.5	6.0	6.5	7.0
4.5	0.718	0.763	0.800	0.820	0.565	-	-	-	-
5.0	0.705	0.749	0.785	0.811	0.591	0.563	-	-	-
5.5	0.690	0.734	0.771	0.797	0.617	0.588	0.560	-	-
6.0	0.674	0.718	0.755	0.782	0.641	0.611	0.583	0.556	-
6.5	0.651	0.697	0.735	0.765	0.662	0.631	0.602	0.575	0.550
7.0	0.627	0.675	0.715	0.750	0.679	0.649	0.620	0.590	0.564

Table XII. Values of B_o.

α_o	B_o
-2.0	1.131
-1.8	1.114
-1.6	1.098
-1.4	1.082
-1.2	1.067
-1.0	1.054
-0.8	1.041
-0.6	1.030
-0.4	1.019
-0.2	1.009
0	1.000
0.2	0.994
0.4	0.987
0.6	0.983
0.8	0.979
1.0	0.976
1.2	0.974
1.4	0.973
1.6	0.972
1.8	0.971
2.0	0.972
2.2	0.974
2.4	0.976
2.6	0.978
2.8	0.980
3.0	0.982
3.2	0.985
3.4	0.989
3.6	0.994
3.8	0.999
4.0	1.005
4.2	1.012
4.4	1.020
4.6	1.028
4.8	1.037
5.0	1.047
5.2	1.057
5.4	1.067
5.6	1.078
5.8	1.090
6.0	1.103
6.2	1.117
6.4	1.132
6.6	1.147
6.8	1.162
7.0	1.179
7.2	1.197
7.4	1.216
7.6	1.235
7.8	1.255
8.0	1.276

Table XIII. Values of C_o.

t/c%	C_o
3.0	0.00745
3.5	0.00753
4.0	0.00761
4.5	0.00770
5.0	0.00780
5.5	0.00790
6.0	0.00800
6.5	0.00810
7.0	0.00820
7.5	0.00830
8.0	0.00840
8.5	0.00851
9.0	0.00862

t/c%	C_o
9.5	0.00874
10.0	0.00886
10.5	0.00898
11.0	0.00910
11.5	0.00921
12.0	0.00932
12.5	0.00944
13.0	0.00957
13.5	0.00970
14.0	0.00983
14.5	0.00997
15.0	0.01010
15.5	0.01025
16.0	0.01040

Table XIV. Values of C_{ds}.

$M-M_D$	C_{ds}	$M-M_D$	C_{ds}	$M-M_D$	C_{ds}	$M-M_D$	C_{ds}
0.01	0.0001	0.11	0.0255	0.21	0.0591	0.31	0.0927
0.02	0.0009	0.12	0.0288	0.22	0.0625	0.32	0.0961
0.03	0.0022	0.13	0.0322	0.23	0.0658	0.33	0.0995
0.04	0.0040	0.14	0.0356	0.24	0.0692	0.34	0.1028
0.05	0.0063	0.15	0.0389	0.25	0.0726	0.35	0.1062
0.06	0.0091	0.16	0.0423	0.26	0.0759	0.36	0.1096
0.07	0.0122	0.17	0.0456	0.27	0.0793	0.37	0.1129
0.08	0.0154	0.18	0.0490	0.28	0.0826	0.38	0.1163
0.09	0.0187	0.19	0.0524	0.29	0.0860	0.39	0.1196
0.10	0.0221	0.20	0.0557	0.30	0.0894	0.40	0.1230

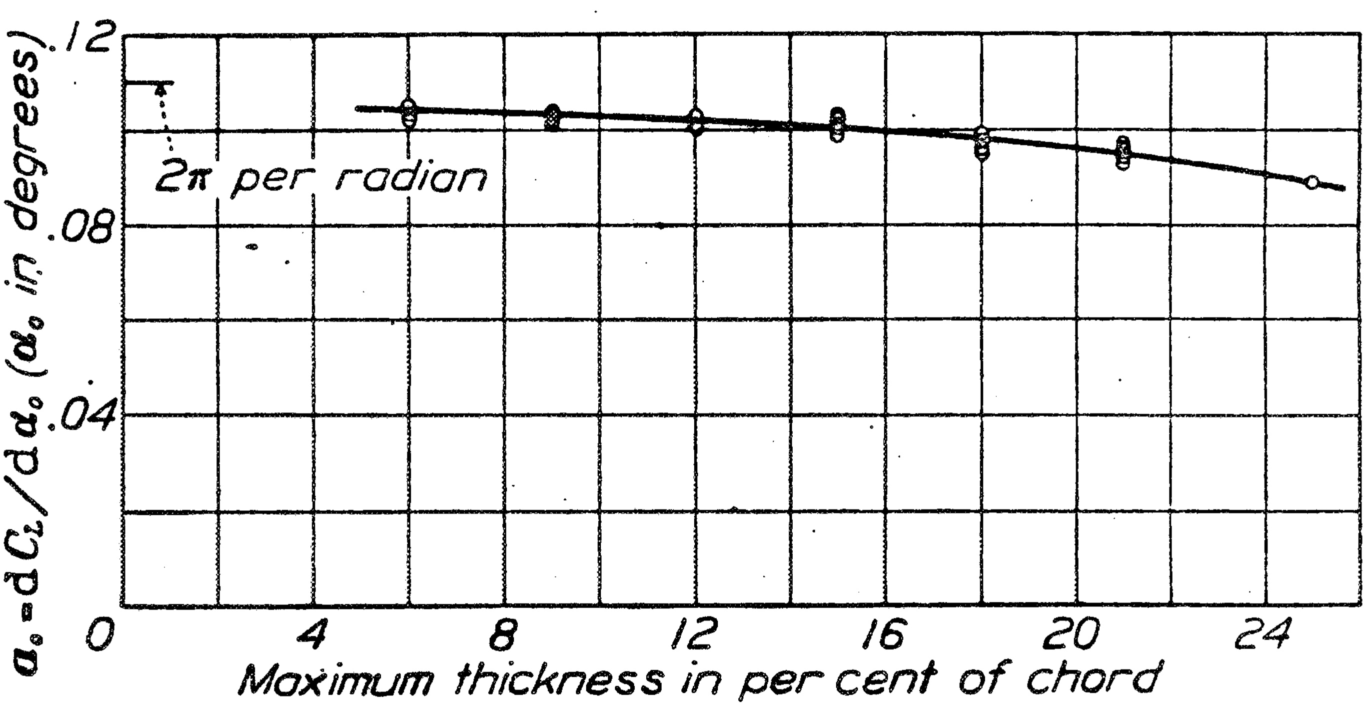

Figure 1. Variation of Lift Curve Slope with Thickness.

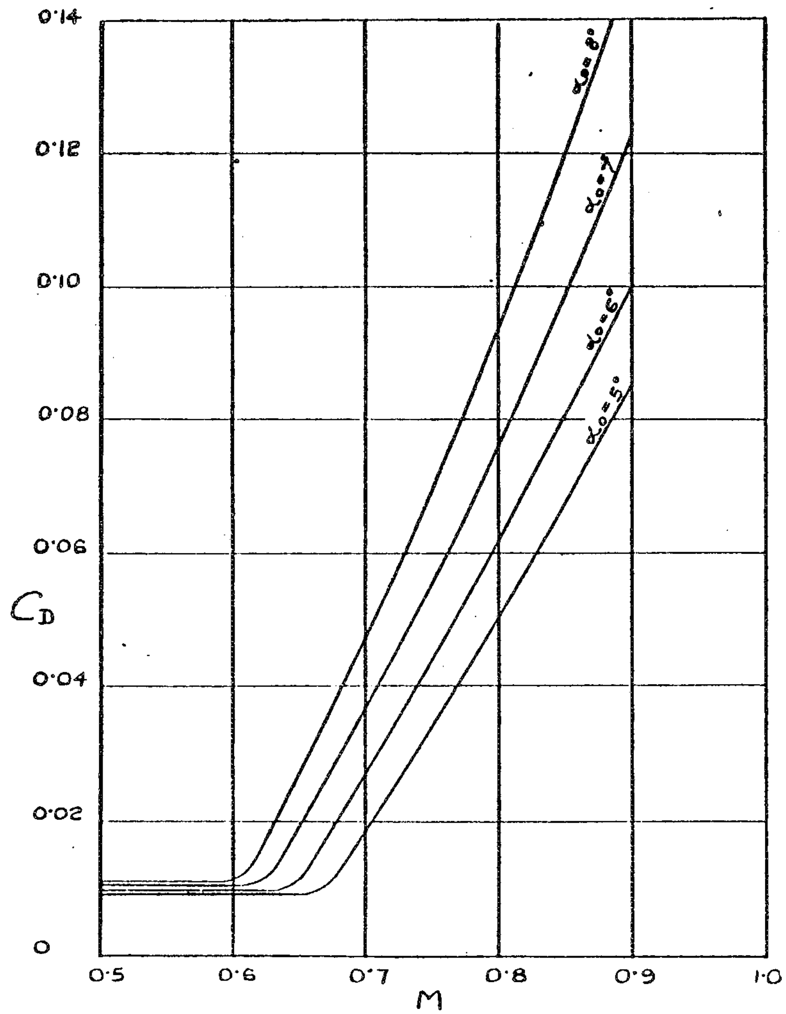

Figure 2. t/c = .09.

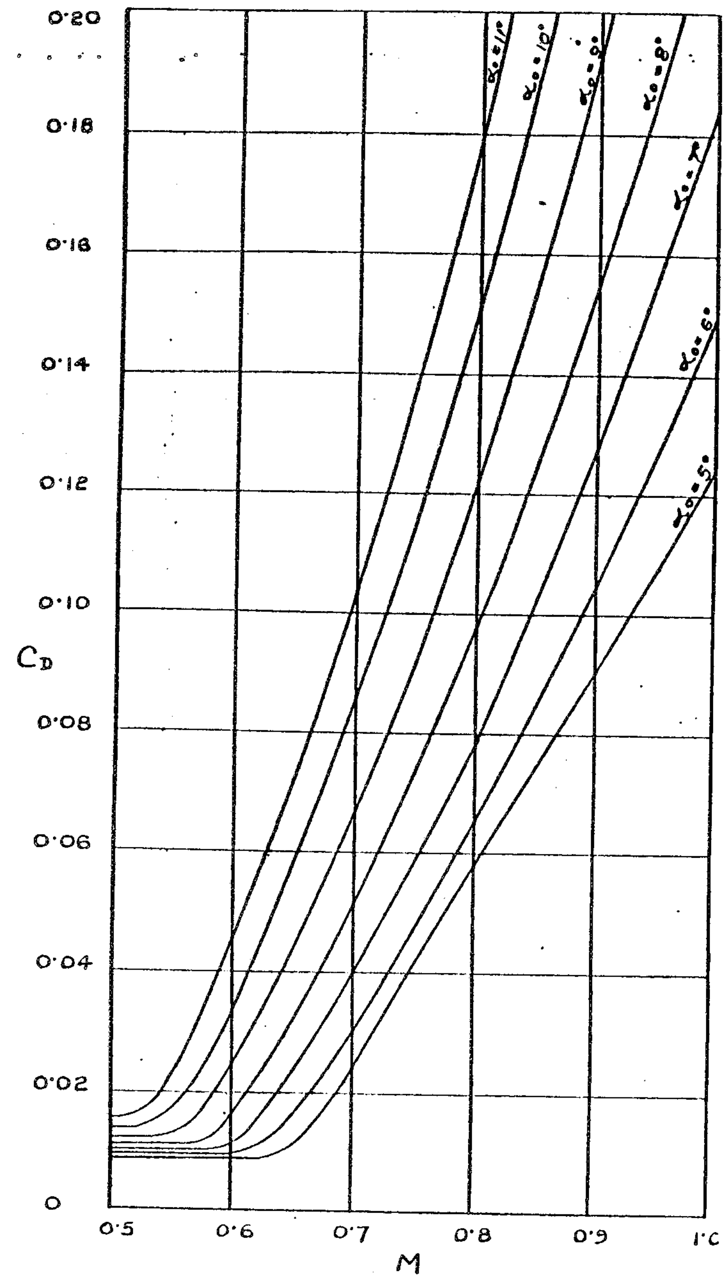

Figure 3. t/c = .1

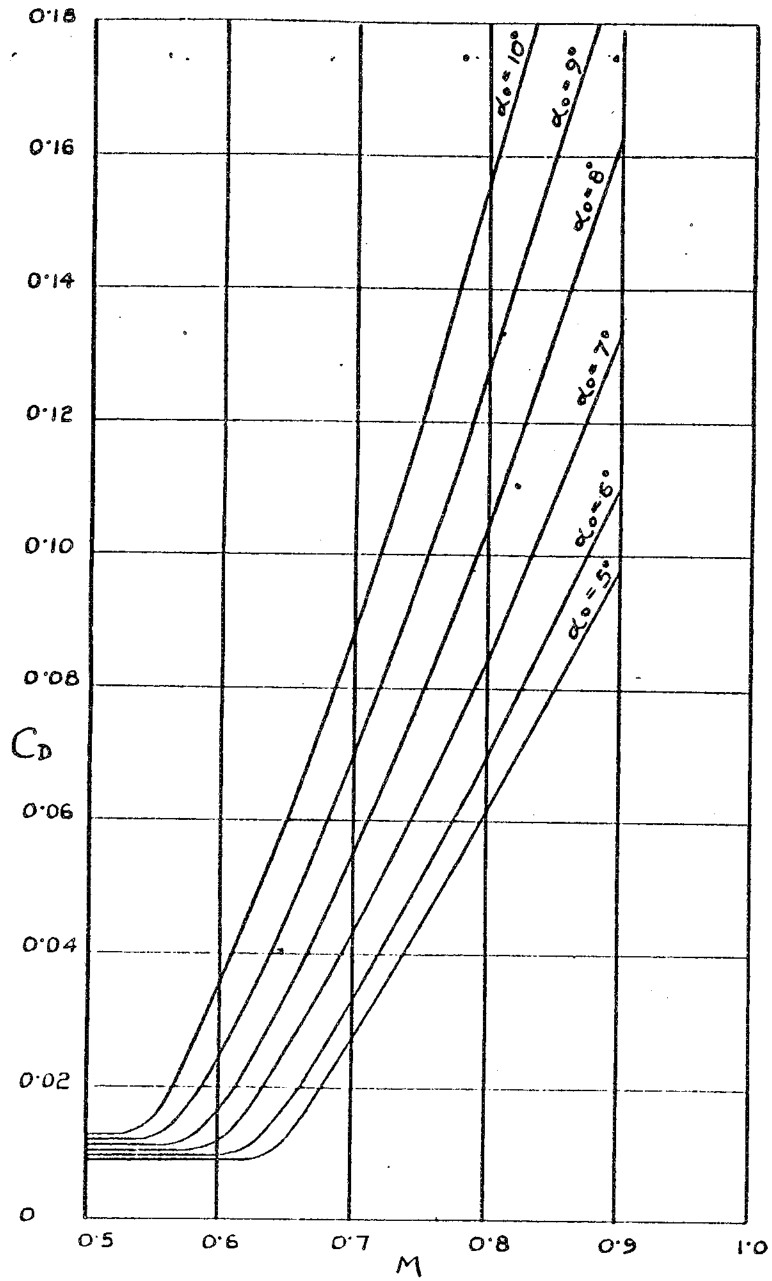

Figure 4. t/c = .11

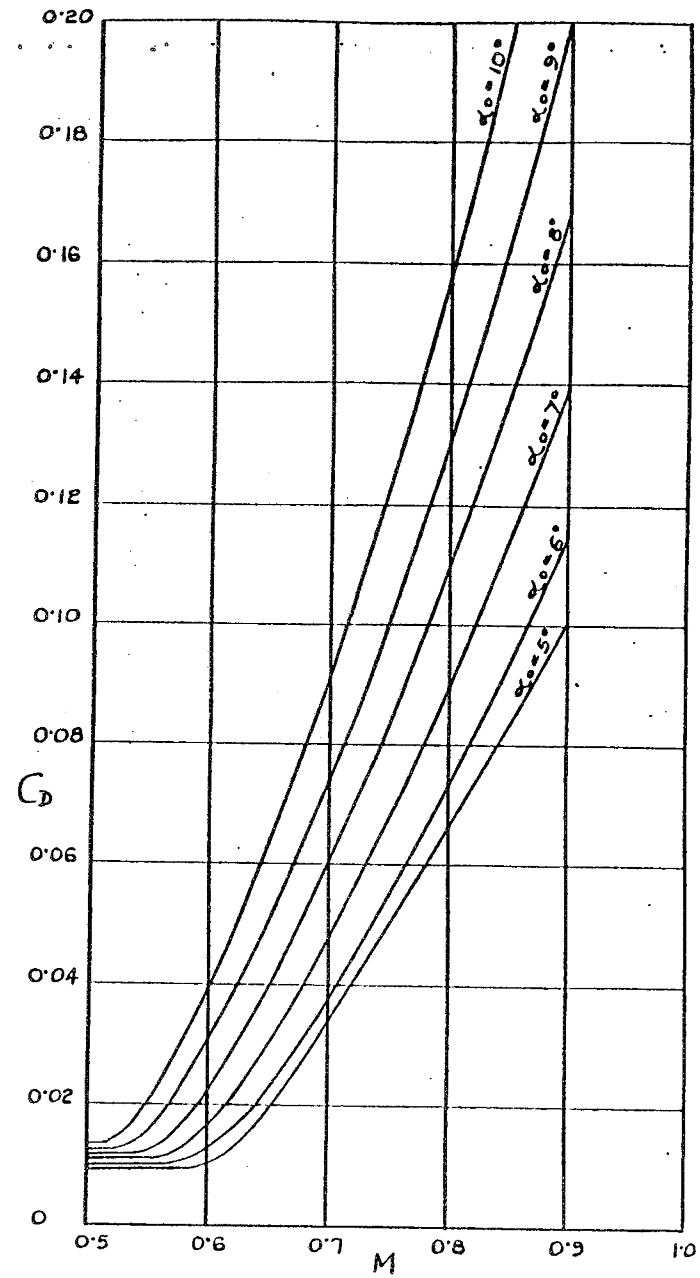

Figure 5. t/c = .12

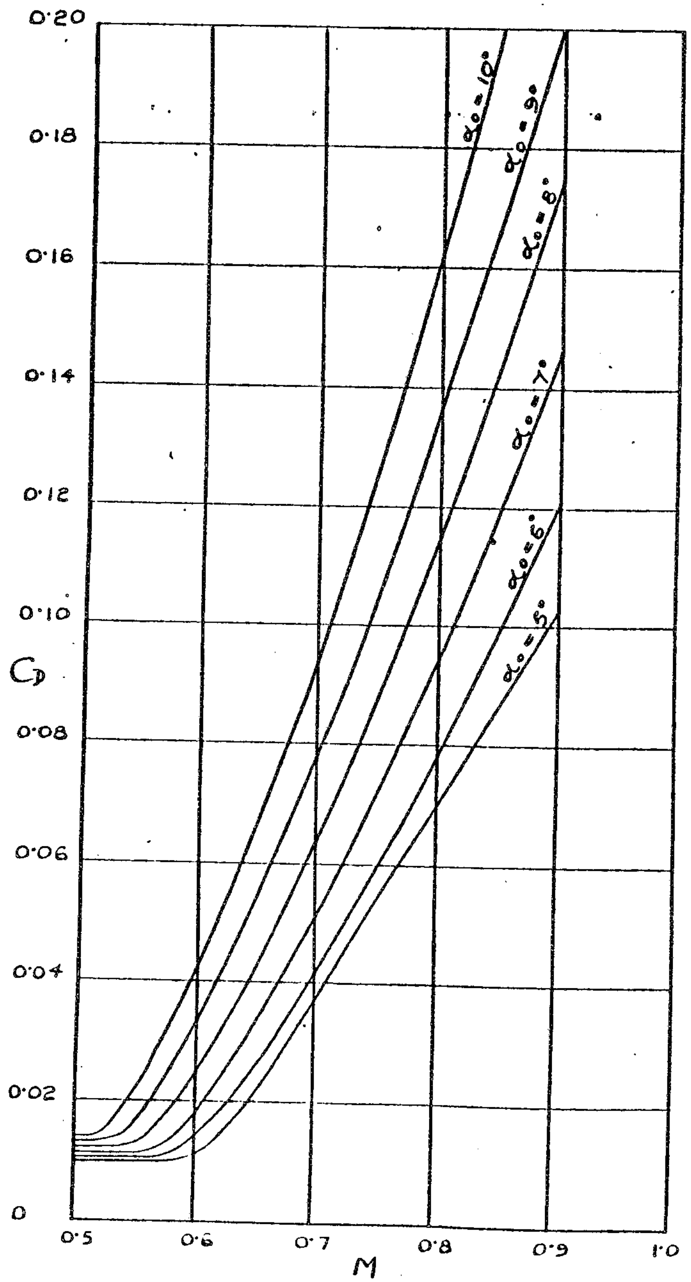

Figure 6. t/c = .13

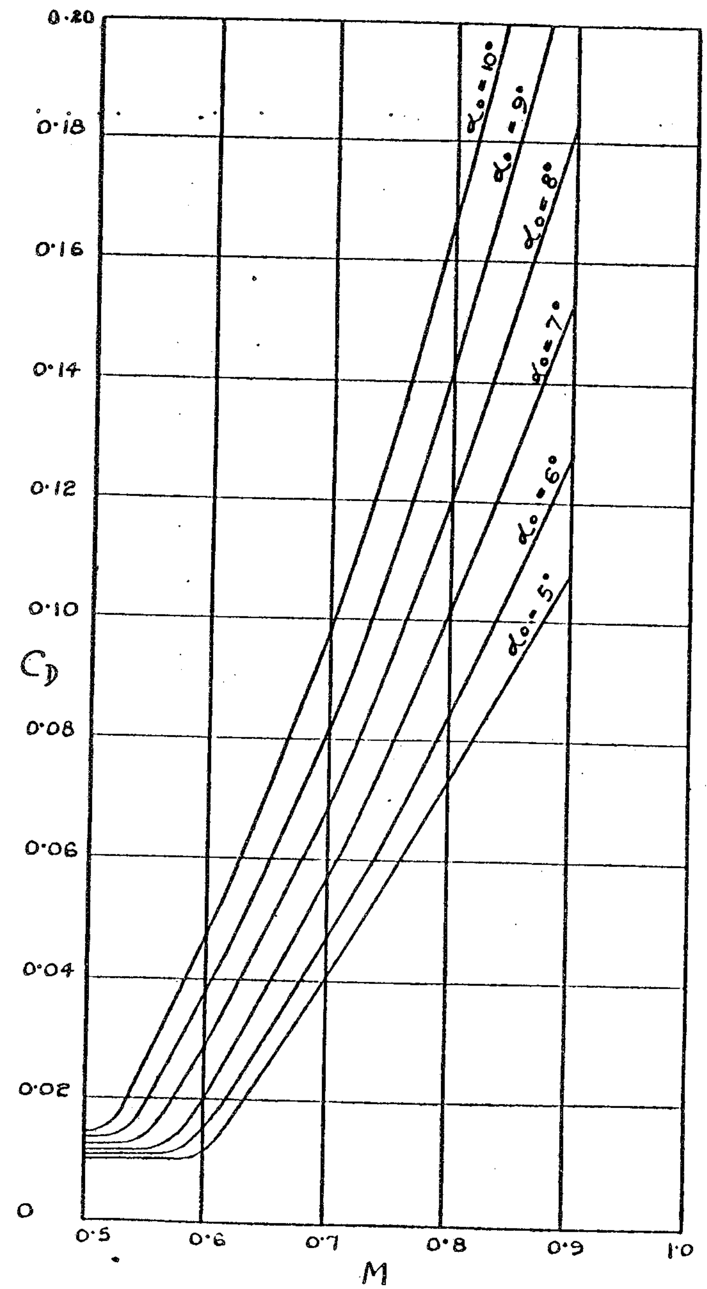

Figure 7. t/c = .14

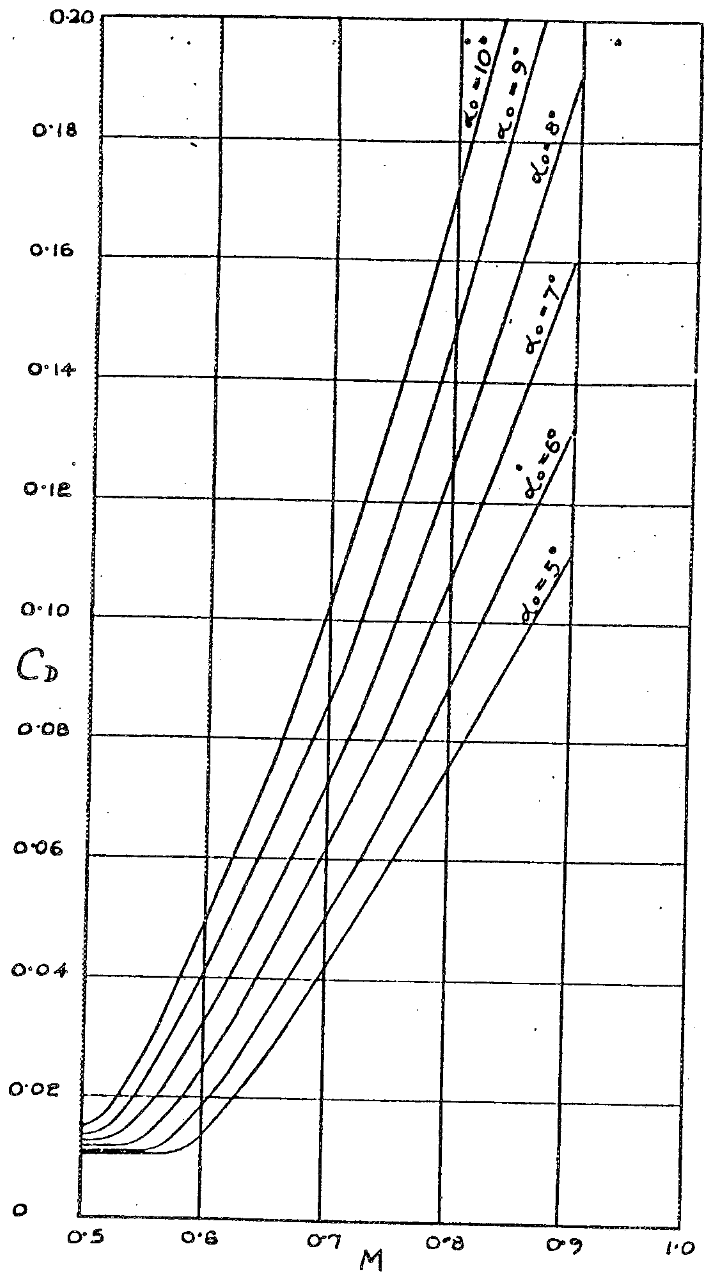

Figure 8. t/c = .15

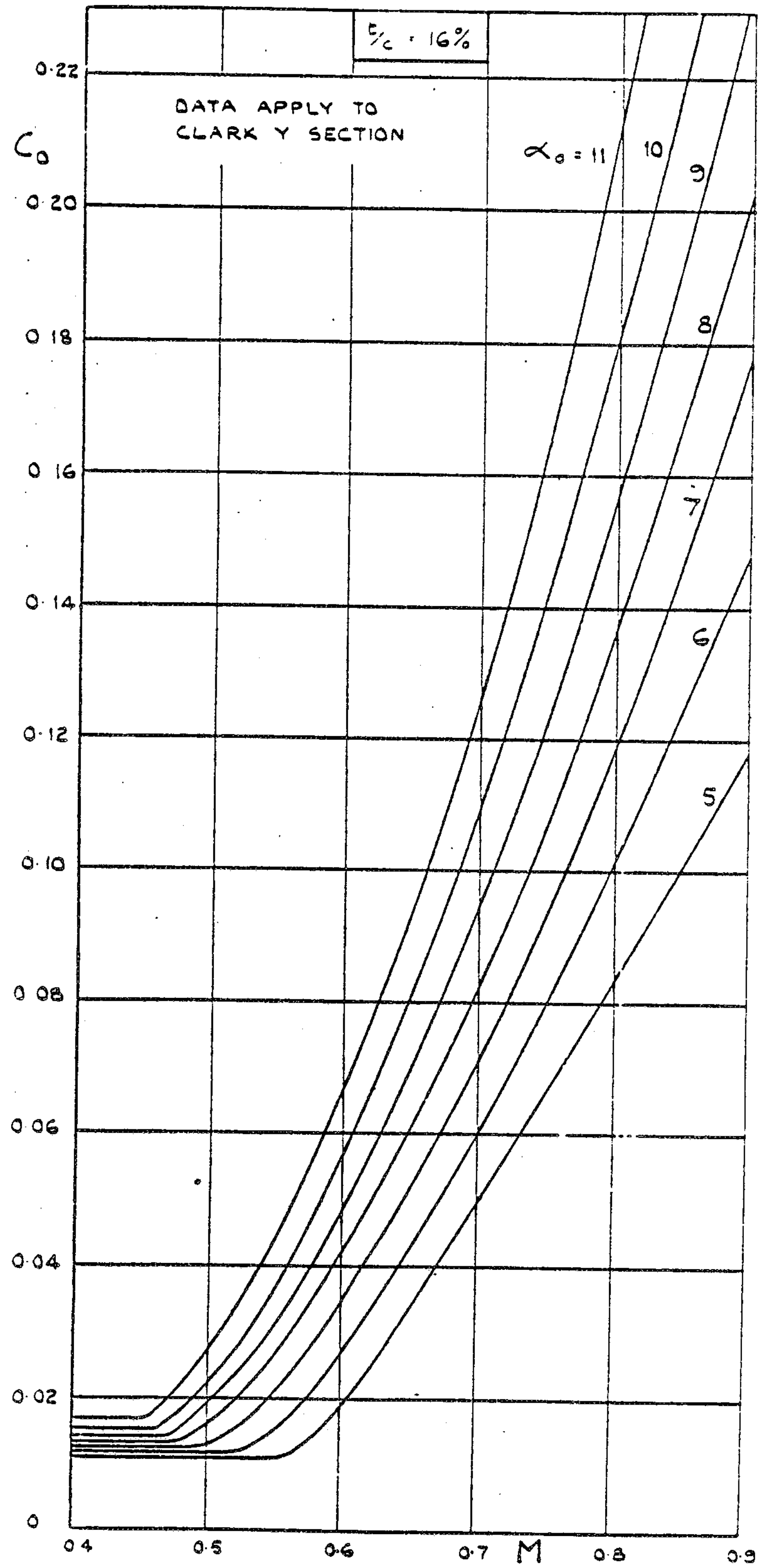

Figure 9. t/c = .16

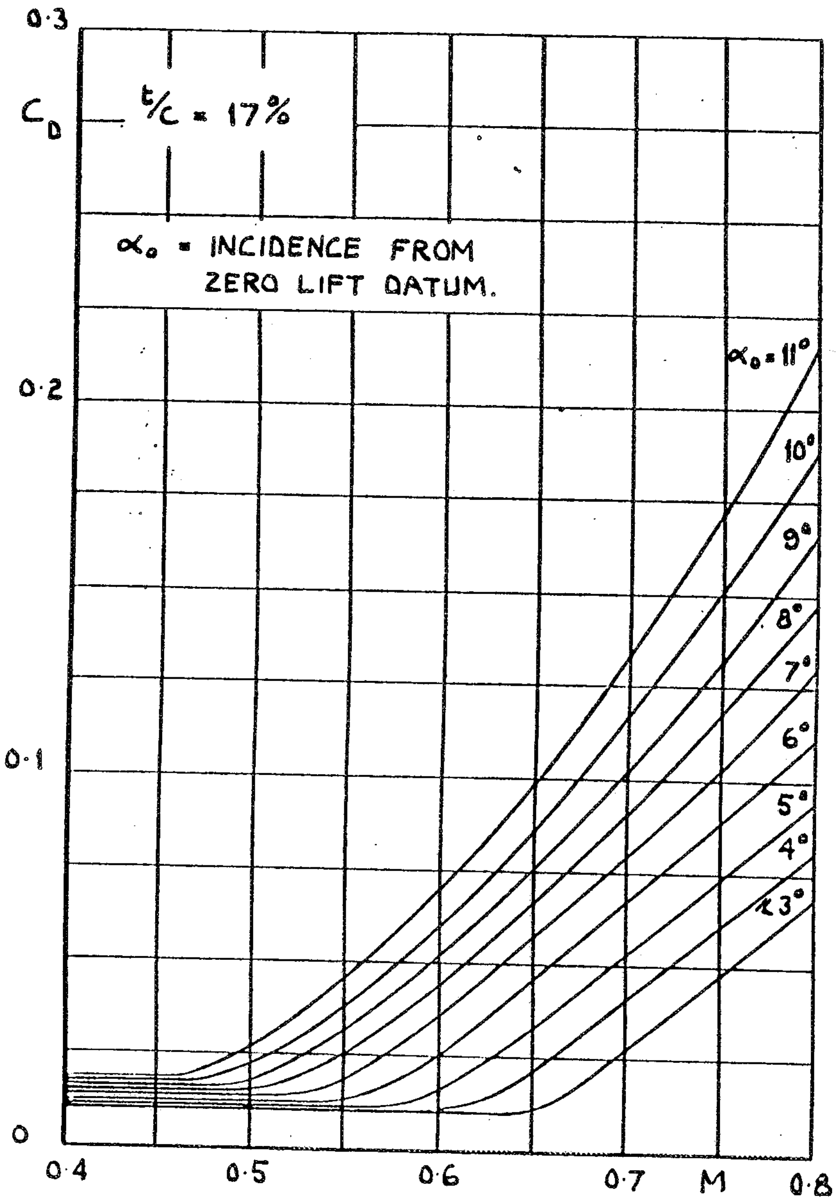

Figure 10. t/c = .17

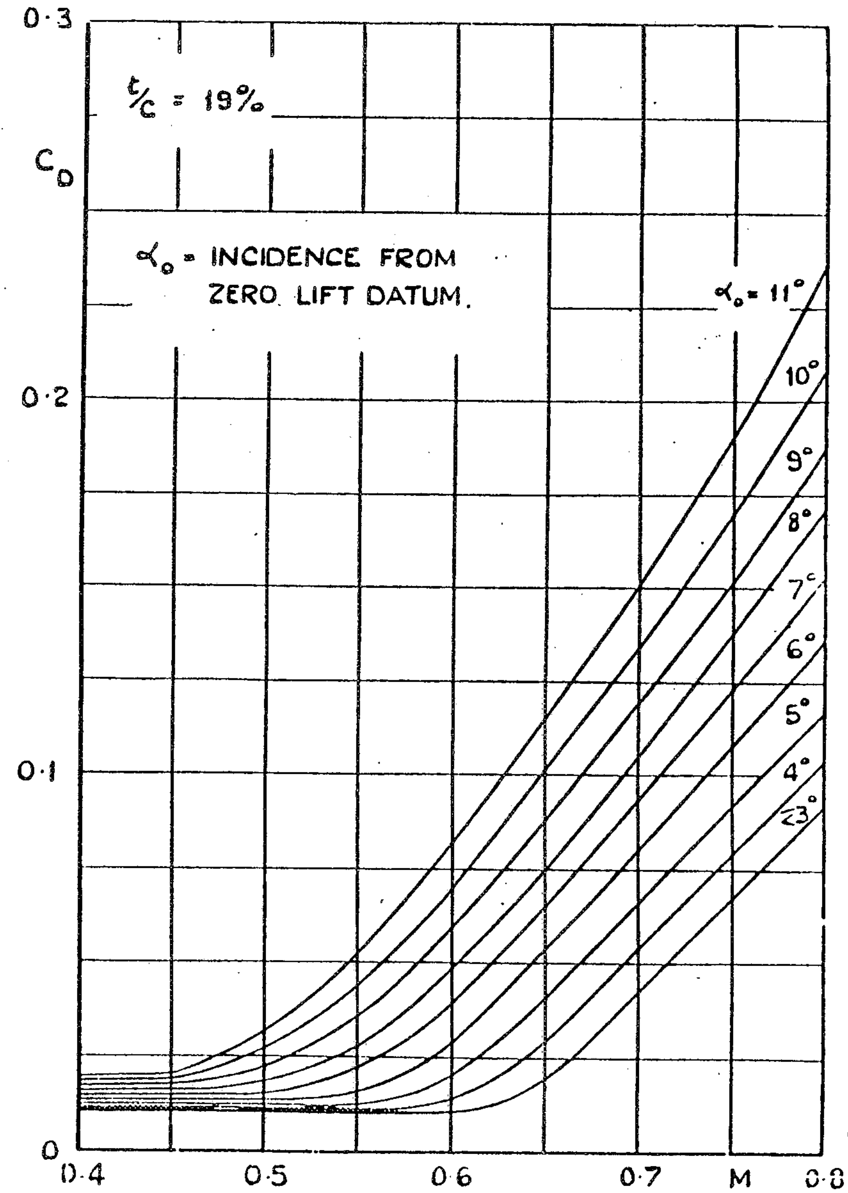

Figure 11. t/c = .19

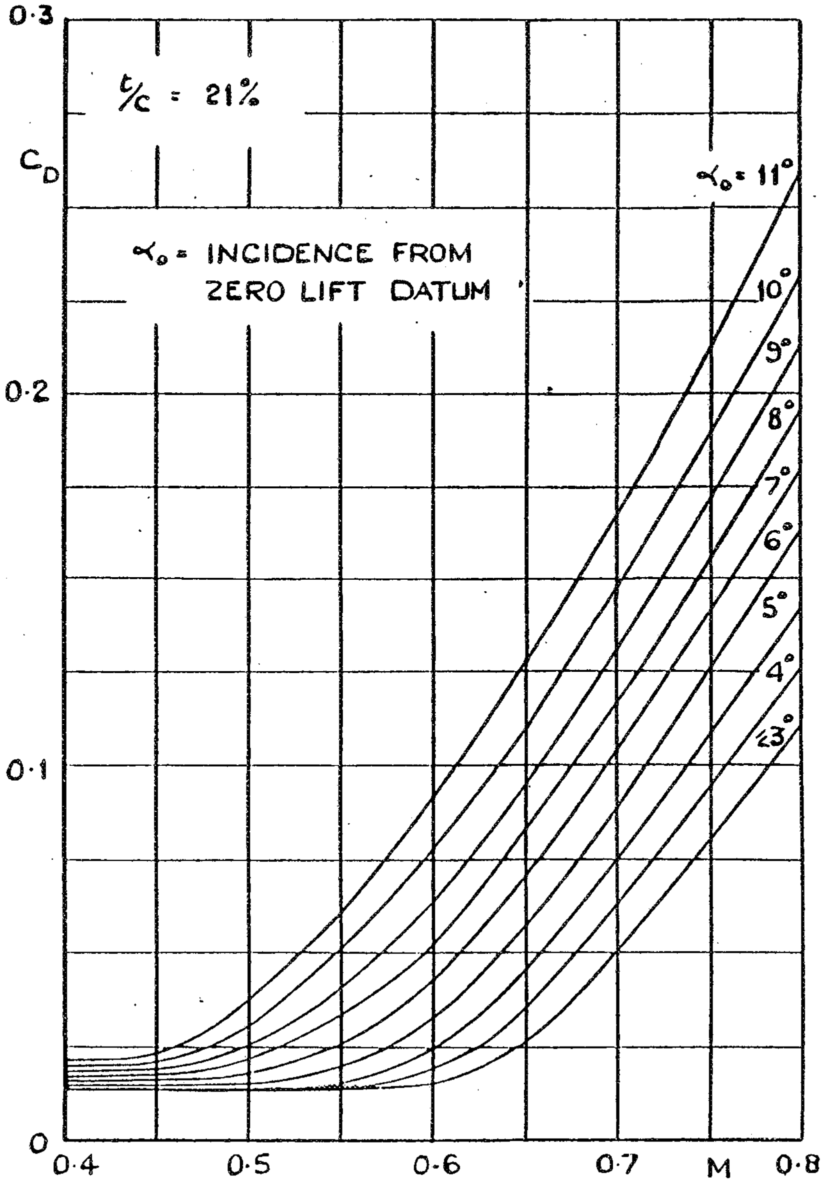

Figure 12. t/c = .21

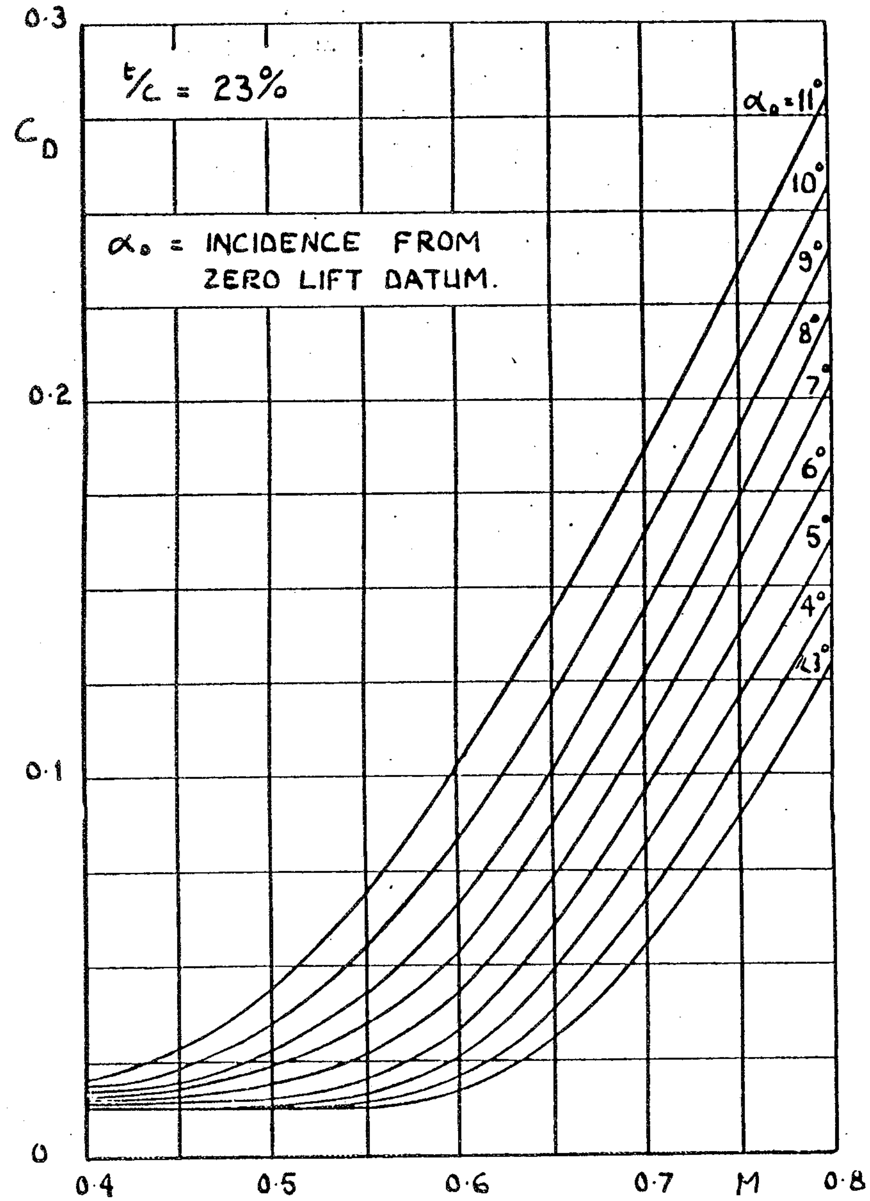

Figure 13. t/c = .23

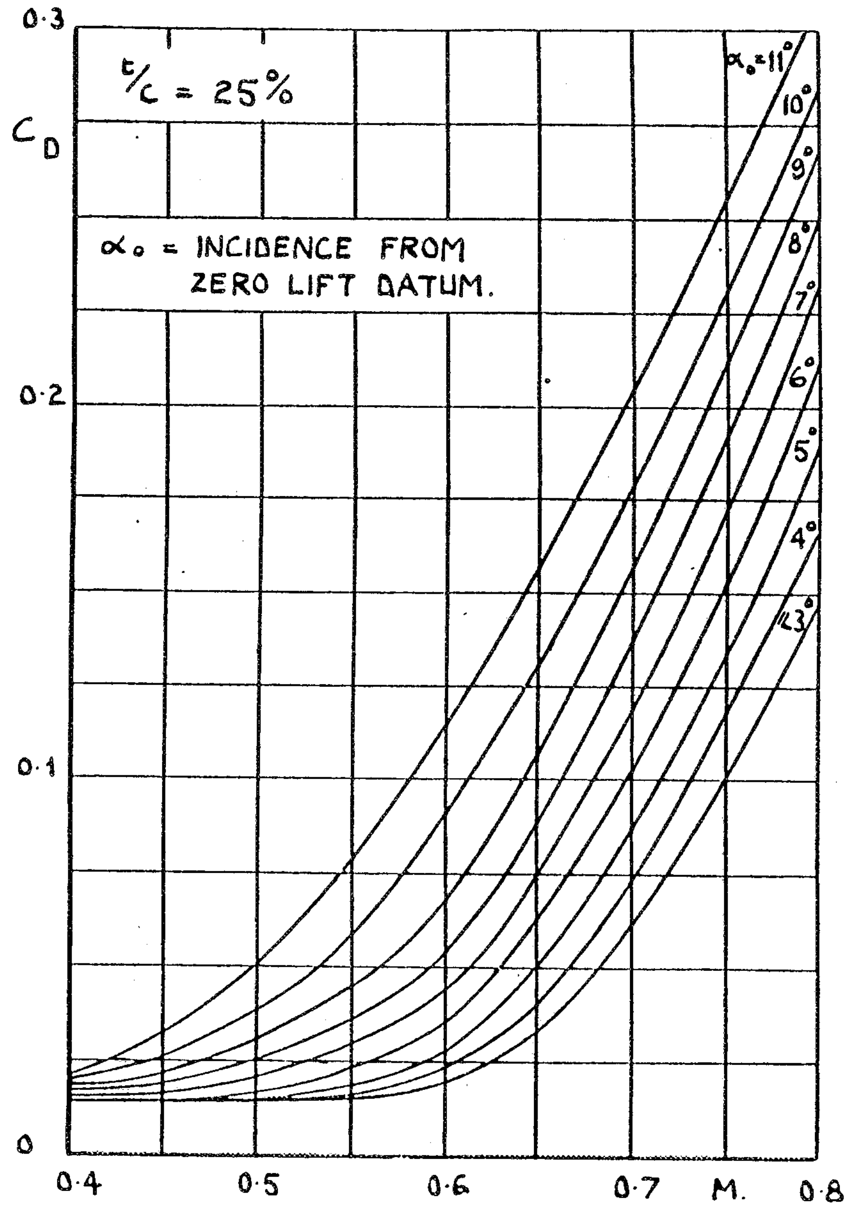

Figure 14. t/c = .25

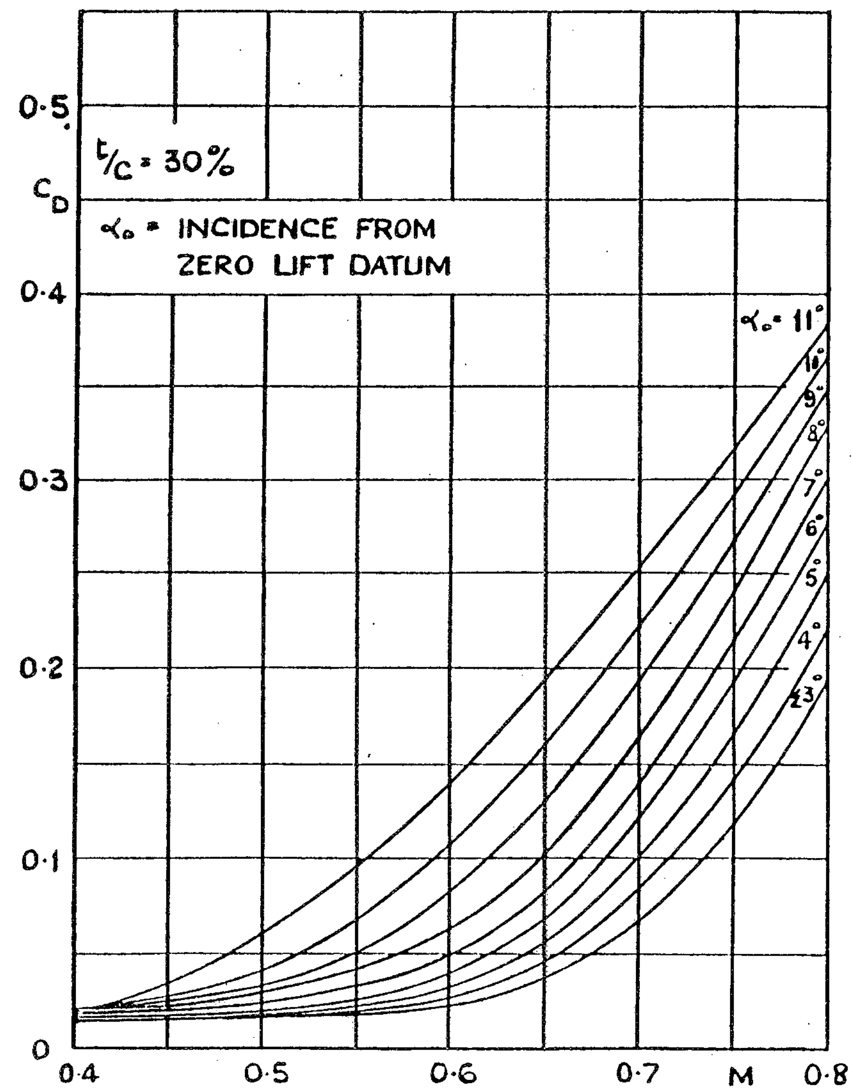

Figure 15. t/c = .30

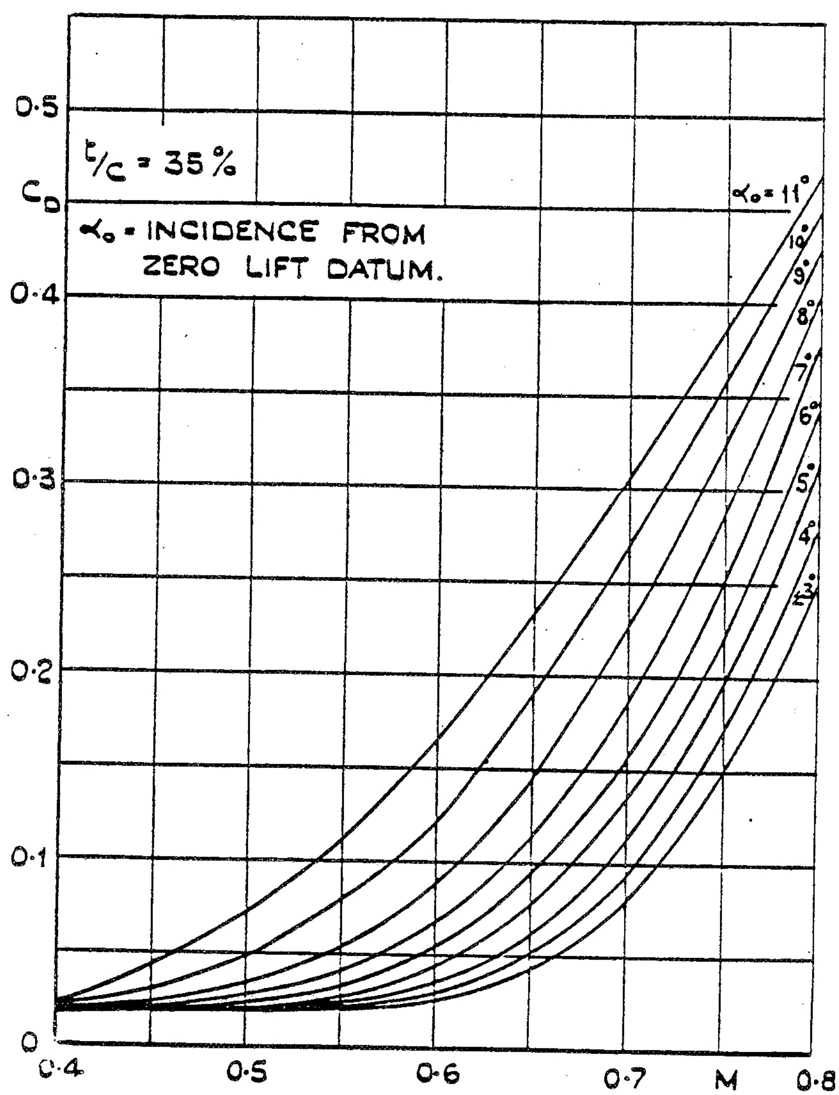

Figure 16. t/c = .35

Appendix I

ClarkY Program Listing

```
//CLARKY JOB (R230,006B,S02,003,A7),'CLARKY'
//*FORMAT PR,DDNAME=,JDE=JFMT1,FORMS=1111
//*XBM WATFIV
//$OPTIONS      NOLIST
C
C*****************************************************************
C*                                                               *
C*   THIS PROGRAM WILL CALCULATE THE LIFT COEFFICIENT, DRAG,    *
C*   AND MOMENT COEFFICIENT ABOUT THE QUARTER CHORD OR THE      *
C*   LEADING EDGE, COORDINATES FOR A CLAYK Y AIRFOIL SECTION    *
C*                                                               *
C*****************************************************************
C
      DIMENSION CL(25,25),CD(25,25),CLD(25,25),ALPHA(7),ALPHAO(21),
     &RN(25),CM(25,25)
      REAL HM(4),NCLD
      DATA HM/0.0,0.1,0.2,0.4/
      DATA ALPHA/-1.0,0.0,1.0,2.0,3.0,4.0,5.0/
      DATA ALTUDE/10000./
C
C   NOTE: CHORD MUST BE IN FEET
C
      DATA CHORD/0.75/
      DATA NUMACH/4/
      DATA NUMALP/7/
      DATA NCL/1/
      DATA NCD/1/
C
      CALL ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
C
C SPECIFY HERE THE KNOWN VALUE OF CLD OR TMAX
C SET THE UNKNOWN VARIABLE (CLD OR (T/C)MAX) EQUAL TO ZERO
C FOR EXAMPLE, NCLD=UNKNOWN VALUE OF CLD,T=KNOWN VALUE OF (T/C)MAX
C NOTE: THIS CLD IS INCOMPRESSIBLE AND ONLY TO START THE CODE.
      DATA NCLD/0.00/
C
C  IN ORDER TO BE CONSISTANT T IS NON-DIMENSIONAL
C
      DATA T/0.1170/
C
      CALL CLTMAX(T,NCLD,ALPHLO,DNCLD)
C
C SPECIFY HERE THE DESIRE FOR CLARK - Y AIRFOIL SECTION COORDINATES
C AND ITS MOMENTS OF INERTIA BY INDICATING "1" FOR "YES", AND "0"
C FOR "NO" FOR PARAMETER "L"
C FOR EXAMPLE, L=1
      DATA L/1/
      CALL CYCOOR(L,CHORD,T)
C
      WRITE(6,10)
   10 FORMAT('1',/////////,56X,'***',1X,'LIMITATIONS',1X,'***'//)
C
C SPECIFY HERE THE DESIRE FOR MOMENT COEFFICIENTS - EITHER CM
C ABOUT THE NOSE OR THE QUARTER CHORD - BY INDICATING "1" FOR
C "CM ABOUT THE NOSE" AND "2" FOR "CM ABOUT THE QUARTER CHORD"
C FOR THE PARAMETER "M".  IF CM IS NOT DESIRED, INDICATE "0" FOR
C PARAMETER "M".
C FOR EXAMPLE, M=1.
      DATA M/2/
C
      DO 21 K=1,NUMACH
C
      DO 42 J=1,NUMALP
C
      RN(K)=DEN*HM(K)*WA*CHORD/VIS
C
      ALPHAO(J)=ALPHA(J)-ALPHLO
      CALL CLCD(ALPHAO(J),T,HM(K),CL(K,J),CD(K,J),NCL,NCD)
      CLD(K,J)=CL(K,J)/CD(K,J)
C
      CM(K,J)=CMFF(T,CL(K,J),M,HM(K))
C
   42 CONTINUE
C
```

```
   21 CONTINUE
C
C
C
      J=0
      IF(NUMACH.EQ.1) GO TO 44
      NUMT=NUMACH
      DO 40 JJ=1,NUMACH
      WRITE(6,892)
  892 FORMAT('1',//////////)
      WRITE(6,852)
  852 FORMAT(' ',14X,'*',1X,'CLARK Y  SERIES AIRFOIL DATA BANK',
     &1X,'*',24X,'*',1X,'CLARK Y  SERIES AIRFOIL DATA BANK',1X,'*'////)
C
      WRITE(6,515) ALTUDE,ALTUDE
  515 FORMAT(T20,'ALTITUDE = ',F10.4,1X,'FEET',T83,'ALTITUDE = '
     &,F10.4,1X,'FEET'/)
      WRITE(6,117) CHORD,CHORD
  117 FORMAT(T23,'CHORD =    ',F10.6,1X,'FEET',T86,'CHORD =    ',
     &F10.6,1X,'FEET'/)
C
      IF(DNCLD.EQ.1.) GO TO 730
C
      WRITE(6,950) T,T,NCLD,NCLD
  950 FORMAT(T20,'(T/C)MAX =    ',F10.6,'    (S)',T82,'(T/C)MAX =    ',
     &F10.6,'    (S)',//T25,'CLD =    ',F10.6,T87,'CLD =    ',F10.6/)
      GO TO 100
C
  730 CONTINUE
      WRITE(6,888) T,T,NCLD,NCLD
  888 FORMAT(T20,'(T/C)MAX =    ',F10.6,T83,'(T/C)MAX =    ',F10.6,
     &//T25,'CLD =    ',F10.6,'    (S)',T88,'CLD =    ',F10.6,'    (S)'/)
C
  100 CONTINUE
      WRITE(6,735) ALPHLO,ALPHLO
  735 FORMAT(T21,'ALPHALO =    ',F10.6,1X,'DEG.',T84,'ALPHALO =    ',
     &F10.6,1X,'DEG.'/)
      WRITE(6,701) HM(J+1),HM(J+2)
  701 FORMAT(T20,'MACH NO. =    ',F10.6,T83,'MACH NO. =    ',F10.6/)
C
      WRITE(6,729)RN(J+1),RN(J+2)
  729 FORMAT(T16,'REYNOLDS NO. =    ',E14.6,T79,'REYNOLDS NO. =    ',
     &E14.6,//)
C
      IF(M.EQ.2) GO TO 82
      WRITE(6,555)
  555 FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(LED)',
     &T73,'ALPHA',T86,'CL',T98,'CD',T108,'CL/CD',T120,'CM(LED)'/)
      GO TO 83
   82 WRITE(6,556)
  556 FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(1/4)',
     &T73,'ALPHA',T86,'CL',T98,'CD',T108,'CL/CD',T120,'CM(1/4)')
   83 CONTINUE
C
      DO 41 N=1,NUMALP
C
      WRITE(6,600) ALPHA(N),CL(J+1,N),CD(J+1,N),CLD(J+1,N),
     &CM(J+1,N),ALPHA(N),CL(J+2,N),CD(J+2,N),CLD(J+2,N),CM(J+2,N)
  600 FORMAT(2(5X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6))
C
   41 CONTINUE
C
      J=JJ*2
      NUMT=NUMT-2
      IF(NUMT.EQ.0) GO TO 33
      IF(NUMT.EQ.1) GO TO 44
C
   40 CONTINUE
C
C
C
   44 WRITE(6,579)
  579 FORMAT('1',//////////)
      WRITE(6,589)
```

```
  589 FORMAT(' ',14X,'*',1X,'CLARK Y  SERIES AIRFOIL DATA BANK',
     &1X,'*'////)
C
      WRITE(6,214) ALTUDE
  214 FORMAT(T20,'ALTITUDE = ',F10.4,1X,'FEET'/)
      WRITE(6,339) CHORD
  339 FORMAT(T23,'CHORD =    ',F10.6,1X,'FEET')
C
      IF(DNCLD.EQ.1.) GO TO 731
C
      WRITE(6,951) T,NCLD
 951  FORMAT(T20,'(T/C)MAX =    ',F10.6,'    (S)',//T25,'CLD =    ',F10.6/)
      GO TO 101
C
  731 CONTINUE
      WRITE(6,889) T,NCLD
 889  FORMAT(T20,'(T/C)MAX =    ',F10.6,//T25,'CLD =    ',F10.6,'    (S)'/)
C
  101 CONTINUE
      WRITE(6,736) ALPHLO
  736 FORMAT(T21,'ALPHLO =    ',F10.6,1X,'DEG.'/)
      WRITE(6,702) HM(NUMACH)
  702 FORMAT(T20,'MACH NO. =    ',F10.6/)
C
      WRITE(6,912)RN(NUMACH)
  912 FORMAT(/T16,'REYNOLDS NO. =    ',E14.6//)
C
      IF(M.EQ.2) GO TO 84
      WRITE(6,666)
  666 FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(LED)'/)
      GO TO 85
  84  WRITE(6,665)
 665  FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(1/4)'/)
  85  CONTINUE
C
      DO 66 N=1,NUMALP
      WRITE(6,250) ALPHA(N),CL(NUMACH,N),CD(NUMACH,N),CLD(NUMACH,N)
     &,CM(NUMACH,N)
  250 FORMAT(5X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6)
  66  CONTINUE
C
      GO TO 33
C
   33 WRITE(6,999)
  999 FORMAT('1',//////////)
      STOP
      END
C
C
C
C
C
C
      SUBROUTINE CLCD(ALPHAO,T,HM,CL,CD,NCL,NCD)
C*****************************************************************
C                                                                *
C                  HIGH-SPEED LIFT AND DRAG DATA                 *
C                             FOR                                *
C                PROPELLER PERFORMANCE CALCULATION               *
C                         CLARK-Y SECTIONS                       *
C                                                                *
C                                                                *
C                    REFERENCES:                                 *
C                                                                *
C     HAINES, A. B. AND MONAGHAN, R. J., "HIGH SPEED LIFT        *
C     AND DRAG DATA FOR PROPELLER PERFORMANCE CALCUALATIONS      *
C     TIONS," R&M NO. 2036, BRITISH A. R. C., 1945.              *
C                                                                *
C     MACDOUGALL, A. R. C., "REVISED HIGH-SPEED LIFT AND         *
C     DRAG DATA FOR PROPELLER PERFORMANCE CALCULATIONS,"         *
C     R&M NO. 2474, BRITISH A. R. C., 1947.                      *
C                                                                *
C----------------------------------------------------------------*
C                                                                *
```

```
C   USAGE:                                                        *
C                                                                 *
C     CALL CLCD(ALPHAO,T,HM,CL,CD,NCL,NCD)                        *
C                                                                 *
C   DESCRIPTION OF PARAMETERS:                                    *
C                                                                 *
C     CL       = LIFT COEFFICIENT                                 *
C     CD       = DRAG COEFFICIENT                                 *
C     ALPHA    = ANGLE OF ATTACK RELATIVE TO FREE STREAM (DEG.)   *
C     ALPHAO   = ANGLE OF ATTACK RELATIVE TO THE ZERO LIFT LINE   *
C                (DEGREES)                                        *
C     T        = THICKNESS-CHORD RATIO WITH RESPECT TO LONGEST    *
C                CHORD LINE                                       *
C     HM       = MACH NUMBER                                      *
C     NCL      = NCL .NE. 0 IF CL DESIRED                         *
C     NCD      = NCD .NE. 0 IF CD DESIRED                         *
C                                                                 *
C................................................................*
C................................................................*
C
      IF(NCL.NE.0) CL=CLFF(ALPHAO,T,HM)
      IF(NCD.NE.0) CD=CDFF(T,ALPHAO,HM)
      RETURN
      END
C
C
C*****************************************************************
C                                                                 *
C                         LIFT DATA                               *
C                                                                 *
C*****************************************************************
C
      FUNCTION CLFF(ALPHAO,T,HM)
C   CLFF  = LIFT COEFFICIENT
C   ALPHAO=ANGLE OF ATTACK RELATIVE TO THE ZERO LIFT LINE
C   T      =THICKNESS-CHORD RATIO
C
      IF(T.LT.0.16) GO TO 1
      CLFF=ALPHAO*THKSLP(T,ALPHAO,HM)
C   THKSLP(T,HM) CALCULATES THE SLOPE OF THE LIFT CURVE
C   FOR THICK SECTIONS
      RETURN
    1 AO=AOF(T,ALPHAO,HM)
C   AOF(T) CALCULATES SLOPE OF LOW-SPEED LIFT CURVE
      HML=HMLF(T,ALPHAO,HM)
C   HMLF(T,ALPHAO,HM) CALCULATES THE CRITICAL MACH NUMBER FOR
C   LIFT. (FUNCTION OF THICKNESS AND ANGLE OF ATTACK)
      H=HM-HML
C   CALCULATE INCOMPRESSIBLE LIFT COEFFICIENT
      CLO=AO*ALPHAO
C   APPLY PRANDTL-GLAUERT CORRECTION
      IF(HM.LE.HML) CLFF=CLO/SQRT(1.-HM*HM)
      IF(H.LE.0.4) GO TO 2
    2 IF(HM.GT.HML)CLFF=CLO/SQRT(1.-HML*HML)+CLSF(H)
C   CLSF(H) CALCULATES THE DIFFERENCE OF CL AT A MACH NUMBER
C   ABOVE THE CRITICAL FROM ITS CRITICAL VALUE.
      RETURN
      END
C
      FUNCTION AOF(T,ALPHAO,HM)
C   AOF= VALUE OF AO, SLOPE OF THE LOW SPEED LIFT CURVE
C   T  = THICKNESS-CHORD RATIO
C
      DIMENSION A(28),H(28),X(3),Y(3)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1174, TABLE #1
C   DATA A = SLOPE OF LOW-SPEED LIFT CURVE
      DATA A/0.1095, 0.1094, 0.1091, 0.1085, 0.1069, 0.1043,
     1       0.1017, 0.0991, 0.0999, 0.0999, 0.0999, 0.0998,
     2       0.0996, 0.0992, 0.0987, 0.0980, 0.0972, 0.0962,
     3       0.0950, 0.0936, 0.0920, 0.0902, 0.0881, 0.0858,
     4       0.0832, 0.0804, 0.0773, 0.0738/
C   DATA H = THICKNESS-CHORD RATIO
      DATA H/0.001,0.002,0.005,0.010,0.025,0.050,0.075,0.100,0.110,
     1       0.120,0.130,0.140,0.150,0.160,0.170,0.180,0.190,0.200,
```

```
      2         0.210,0.220,0.230,0.240,0.250,0.260,0.270,0.280,0.290,
      3         0.300/
       TCMAX=0.3
       IF(T.GT.TCMAX) WRITE(6,30) T,TCMAX
   30 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
      &F10.6,' OF FUNCTION AOF'/)
       N=2
       AOF=0.1096
       IF(T.EQ.0.) RETURN
       IS=1
       IL=IS+N-1
    1  IF(IL.GE.28) GO TO 2
       IF((T-H(IS))*(T-H(IL)).LE.0.) GO TO 3
       IS=IL
       IL=IS+N-1
       GO TO 1
     2 IS=28-N+1
       IL=28
     3 DO 4 I=IS,IL
       X(I-IS+1)=H(I)
       Y(I-IS+1)=A(I)
     4 CONTINUE
       AOF=YLAGN(X,Y,N,T)
       RETURN
       END
C
       FUNCTION CLSF(H)
C    CLSF=CLS
C    H   =M-ML
C
       DIMENSION C(40),S(40),X(3),Y(3)
C    DATA IS FROM HAINES AND MONAGHAN, P. 1176, TABLE #4
C    DATA C = LIFT COEFFICIENT
       DATA C/ 0.010, 0.017, 0.022, 0.025, 0.026, 0.025, 0.021,
      1          0.015, 0.007,-0.002,-0.014,-0.027,-0.040,-0.054,
      2         -0.070,-0.086,-0.102,-0.119,-0.138,-0.157,-0.175,
      3         -0.193,-0.212,-0.231,-0.250,-0.270,-0.289,-0.307,
      4         -0.325,-0.344,-0.363,-0.381,-0.400,-0.417,-0.432,
      5         -0.446,-0.459,-0.470,-0.478,-0.485/
C    DATA S = (M-ML), WHERE M=LOCAL MACH NO., AND ML=CRITICAL MACH NO.
C    FOR LIFT AT WHICH THE LIFT DEPARTS FROM THE GLAUERT LAW, VARIED
C    WITH (T/C) AND ALPHAO
       DATA S/0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09,0.10,
      1         0.11,0.12,0.13,0.14,0.15,0.16,0.17,0.18,0.19,0.20,
      2         0.21,0.22,0.23,0.24,0.25,0.26,0.27,0.28,0.29,0.30,
      3         0.31,0.32,0.33,0.34,0.35,0.36,0.37,0.38,0.39,0.40/
       HMIN=0.01
       HMAX=0.40
       IF(H.LT.HMIN) WRITE(6,10) H,HMIN
   10  FORMAT(' ',19X,'H = M-ML = ',F10.6,' IS LESS THAN HMIN = ',
      &F10.6,' OF FUNCTION CLSF'/)
       IF(H.GT.HMAX) WRITE(6,20) H,HMAX
   20  FORMAT(' ',19X,'H = M-ML = ',F10.6,' IS GREATER THAN HMAX = ',
      &F10.6,' OF FUNCTION CLSF'/)
       N=3
       IS=1
       IL=IS+N-1
       IF(H.LE.S(IL)) GO TO 1
       IL=40
       IS=IL-N+1
       IF(H.GE.S(IS)) GO TO 1
       IS=1
       IL=IS+N-1
     2 IF(((H-S(IS))*(H-S(IL))).LE.0.) GO TO 1
       IS=IL
       IL=IS+N-1
       GO TO 2
     1 DO 4 I=IS,IL
       X(I-IS+1)=S(I)
       Y(I-IS+1)=C(I)
     4 CONTINUE
       CLSF=YLAGN(X,Y,N,H)
       RETURN
       END
```

```
C
      FUNCTION THKSLP(T,ALPHAO,HM)
C THKSLP = VALUE OF THE SLOPE OF THE LIFT CURVE OF THE
C          THICK SECTION
C T      = THICKNESS-CHORD RATIO
C HM     = SECTION MACH NUMBER
C
      DIMENSION H(6),S(9),X(3),Y(3),U(3),V(3)
      DIMENSION A15(6),A17(5),A19(4)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1176, TABLE #5
C   DATA 'A.NO.': 'A'=INVERSE SLOPE OF LOW=SPEED LIFT CURVE, '.NO.'=
C   THICKNESS-CHORD RATIO
      DATA A15/9.2,8.95,8.7,8.4,8.0,7.9/
      DATA A17/9.6,9.4,9.2,8.95, 8.8/
      DATA A19/10.1,10.0,9.9,9.8/
C   DATA H = MACH NO.
      DATA H/0.40,0.45,0.50,0.55,0.60,0.65/
C   DATA S = THICKNESS-CHORD RATIO
      DATA S/0.15,0.17,0.19,0.21,0.23,0.25,0.30,0.35,0.40/
      TCMAX=0.40
      HMAX=0.80
      IF(T.GT.TCMAX) WRITE(6,33) T,TCMAX
   33 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION THKSLP'/)
      IF(HM.GT.HMAX) WRITE(6,70) HM,HMAX
   70 FORMAT(' ',19X,'MACH NO. = ',F10.6,' IS GREATER THAN MACH NO.',
     &'(MAX) = ',F10.6,' OF FUNCTION THKSLP'/)
      IF(HM.LT.0.3) GO TO 50
      CALL OUT(9,2,IS,IL,S,T)
      CALL OUT(6,2,JS,JL,H,HM)
      U(1)=H(JS)
      U(2)=H(JL)
      X(1)=S(IS)
      X(2)=S(IL)
      DO 10 I=IS,IL
C   COMPUTED GO TO
      GO TO (15,17,19,21,23,25,30,35,40),I
   15 ANS=A15(1)
      IF(HM.LE.H(1)) GO TO 1
      ANS=A15(6)
      IF(HM.GE.H(6)) GO TO 1
      V(1)=A15(JS)
      V(2)=A15(JL)
      GO TO 2
   17 ANS=A17(1)
      IF(HM.LE.H(1)) GO TO 1
      ANS=A17(5)
      IF(HM.GE.H(5)) GO TO 1
      V(1)=A17(JS)
      V(2)=A17(JL)
      GO TO 2
   19 ANS=A19(1)
      IF(HM.LE.H(1)) GO TO 1
      ANS=A19(4)
      IF(HM.GE.H(4)) GO TO 1
      V(1)=A19(JS)
      V(2)=A19(JL)
      GO TO 2
   21 ANS=10.5
      GO TO 1
   23 ANS=10.9
      GO TO 1
   25 ANS=11.4
      GO TO 1
   30 ANS=13.6
      GO TO 1
   35 ANS=19.2
      GO TO 1
   40 ANS=30.0
      GO TO 1
    2 ANS=YLAGN(U,V,2,HM)
    1 Y(I-IS+1)=ANS
   10 CONTINUE
      THKSLP=1./YLAGN(X,Y,2,T)
```

```
      RETURN
   50 THKSLP=AOF(T,ALPHAO,HM)
      RETURN
      END
C
C
C
      FUNCTION HMLF(T,ALPHAO,HM)
C
C HMLF = ML
C T    = THICKNESS-CHORD RATIO
C ALPHAO = ANGLE OF ATTACK RELATIVE TO THE ZERO LIFT LINE
C          (DEGREES)
C
      DIMENSION A(17),B(25),C(25,17),X(3),Y(3),U(3),V(3),
     1 E(6,10),F(10),G(6)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1175, TABLE #3 .
C   DATA A = ALPHAO = ANGLE OF ATTACK WITH RESPECT TO ZERO LIFT LINE
      DATA A/3.,3.5,4.,4.5,5.,5.5,6.,6.5,7.,7.5,8.,8.5,9.,
     1 9.5,10.,10.5,11./
C   DATA B = THICKNESS-CHORD RATIO
      DATA B/0.04,0.045,0.05,0.055,0.06,0.065,0.07,0.075,0.08,
     1 0.085,0.09,0.095,0.10,0.105,0.11,0.115,0.12,0.125,0.13,
     2 0.135,0.14,0.145,0.15,0.155,0.16/
C   DATA C = CIRTICAL MACH NO. FOR LIFT AT WHICH THE LIFT DEPARTS
C   FROM THE GLAUERT LAW, VARIED WITH (T/C) AND ALPHAO
      DATA (C(I,1),I=1,25)/
     1 0.879,0.858,0.83125,0.8125,0.79125,0.7775,0.765,
     1 0.751,0.742,0.732,0.723,0.713,0.704,0.695,0.686,0.677,
     1 0.669,0.660,0.651,0.643,0.635,0.627,0.618,0.610,0.603/
      DATA(C(I,2),I=1,25)/
     2 0.874,0.852,0.828,0.807,0.790,0.775,0.764,0.751,0.742,
     2 0.732,0.723,0.713,0.704,0.695,0.686,0.677,0.669,0.660,
     2 0.651,0.643,0.635,0.627,0.618,0.610,0.603/
      DATA (C(I,3),I=1,25)/
     3 0.867,0.846,0.825,0.804,0.7875,0.773,0.765,0.749,0.740,
     3 0.730,0.721,0.711,0.702,0.694,0.685,0.676,0.668,0.658,
     3 0.649,0.641,0.633,0.625,0.616,0.608,0.601/
      DATA (C(I,4),I=1,25)/
     4 0.859,0.838,0.817,0.798,0.78125,0.768,0.756,0.745,0.735,
     4 0.725,0.716,0.707,0.698,0.689,0.680,0.671,0.663,0.654,
     4 0.645,0.637,0.628,0.620,0.611,0.603,0.596/
      DATA (C(I,5),I=1,25)/
     5 0.848,0.828,0.807,0.789,0.774,0.761,0.749,0.738,0.728,
     5 0.718,0.709,0.699,0.689,0.680,0.671,0.663,0.654,0.646,
     5 0.637,0.627,0.618,0.612,0.602,0.593,0.585/
      DATA (C(I,6),I=1,25)/
     6 0.836,0.817,0.797,0.780,0.765,0.752,0.740,0.729,0.719,
     6 0.709,0.699,0.689,0.679,0.669,0.660,0.650,0.641,0.631,
     6 0.621,0.611,0.600,0.589,0.578,0.568,0.559/
      DATA (C(I,7),I=1,25)/
     7 0.823,0.805,0.787,0.771,0.755,0.742,0.730,0.719,0.707,
     7 0.697,0.687,0.675,0.666,0.656,0.646,0.635,0.625,0.614,
     7 0.603,0.591,0.579,0.567,0.555,0.543,0.532/
      DATA (C(I,8),I=1,25)/
     8 0.808,0.792,0.775,0.760,0.744,0.731,0.718,0.706,0.695,
     8 0.684,0.674,0.663,0.652,0.641,0.629,0.618,0.607,0.595,
     8 0.584,0.572,0.560,0.548,0.536,0.524,0.513/
      DATA (C(I,9),I=1,25)/
     9 0.794,0.778,0.762,0.745,0.730,0.717,0.704,0.691,0.679,
     9 0.667,0.657,0.646,0.635,0.623,0.611,0.600,0.588,0.577,
     9 0.565,0.553,0.541,0.530,0.518,0.507,0.496/
      DATA (C(I,10),I=1,25)/
     $ 0.781,0.765,0.748,0.731,0.716,0.702,0.689,0.676,0.663,
     $ 0.651,0.640,0.628,0.617,0.605,0.593,0.582,0.570,0.558,
     $ 0.546,0.533,0.523,0.513,0.502,0.492,0.483/
      DATA (C(I,11),I=1,25)/
     1 0.768,0.752,0.734,0.717,0.701,0.687,0.673,0.661,0.648,
     1 0.635,0.622,0.611,0.599,0.587,0.575,0.563,0.551,0.539,
     1 0.528,0.517,0.507,0.498,0.489,0.479,0.470/
      DATA (C(I,12),I=1,25)/
     2 0.755,0.739,0.720,0.703,0.685,0.670,0.656,0.644,0.631,
     2 0.618,0.606,0.593,0.580,0.568,0.556,0.545,0.534,0.523,
     2 0.513,0.503,0.493,0.484,0.474,0.466,0.457/
```

```
      DATA (C(I,13),I=1,25)/
     3 0.742,0.726,0.706,0.689,0.667,0.652,0.638,0.626,0.613,
     3 0.601,0.588,0.575,0.563,0.551,0.539,0.528,0.518,0.508,
     3 0.498,0.489,0.479,0.471,0.462,0.454,0.446/
      DATA (C(I,14),I=1,25)/
     4 0.729,0.713,0.692,0.675,0.647,0.633,0.620,0.608,0.595,
     4 0.583,0.570,0.558,0.546,0.535,0.524,0.513,0.503,0.494,
     4 0.484,0.475,0.467,0.460,0.453,0.446,0.439/
      DATA (C(I,15),I=1,25)/
     5 0.716,0.700,0.678,0.661,0.625,0.613,0.601,0.589,0.576,
     5 0.564,0.552,0.541,0.530,0.519,0.509,0.499,0.490,0.481,
     5 0.473,0.465,0.458,0.451,0.445,0.438,0.432/
      DATA (C(I,16),I=1,25)/
     6 0.703,0.687,0.664,0.647,0.601,0.592,0.582,0.570,0.558,
     6 0.547,0.536,0.526,0.516,0.505,0.496,0.487,0.479,0.471,
     6 0.463,0.457,0.450,0.444,0.439,0.432,0.426/
      DATA (C(I,17),I=1,25)/
     7 0.690,0.674,0.650,0.633,0.575,0.570,0.564,0.552,0.541,
     7 0.531,0.521,0.511,0.502,0.493,0.485,0.477,0.470,0.463,
     7 0.456,0.450,0.445,0.439,0.433,0.427,0.422/
C    DATA IS FROM MACDOUGALL, PP. 1032-33, TABLES 1A&B
C    DATA F = ALPHAO = ANGLE OF ATTACK WITH RESPECT TO ZERO LIFT LINE
      DATA F/-1.5,-1.,-0.5,0.,0.5,1.,1.5,2.,2.5,3./
C    DATA G = THICKNESS-CHORD RATIO
      DATA G/0.045,0.05,0.055,0.06,0.065,0.07/
C    DATA E = CIRTICAL MACH NO. FOR DRAG AT WHICH THE DRAG DEPARTS
C    FROM ITS LOW-SPEED VALUE
      DATA ((E(I,II),I=1,6),II=1,5)/
     1 0.584,0.593,0.603,0.613,0.625,0.638,
     2 0.586,0.601,0.610,0.62125,0.63125,0.64375,
     3 0.603,0.61875,0.63125,0.64,0.65875,0.6662,
     4 0.64625,0.6620,0.67425,0.6875,0.69375,0.696875,
     5 0.7,0.7125,0.725,0.73525,0.73125,0.73125/
      DATA ((E(I,II),I=1,6),II=6,10)/
     6 0.775,0.775,0.775,0.77625,0.7575,0.75,
     7 0.8125,0.80625,0.778125,0.7775,0.76875,0.7593,
     8 0.840,0.82125,0.805,0.7875,0.776,0.765,
     9 0.852,0.827,0.80875,0.790,0.775,0.7656,
     1 0.858,0.83125,0.8125,0.79125,0.7775,0.765/
      TCMIN=0.04
      TCMAX=0.16
      ALOMIN=-1.5
      ALOMAX=11.0
      IF(T.LT.TCMIN) WRITE(6,21) T,TCMIN
   21 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' OF FUNCTION HMLF'/)
      IF(T.GT.TCMAX) WRITE(6,30) T,TCMAX
   30 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION HMLF'/)
      IF(ALPHAO.LT.ALOMIN) WRITE(6,40) ALPHAO,ALOMIN
   40 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS LESS THAN',
     &' ALPHAOMIN = ',F10.6,' OF FUNCTION HMLF'/)
      IF(ALPHAO.GT.ALOMAX) WRITE(6,50) ALPHAO,ALOMAX
   50 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS GREATER',
     &' THAN ALPHAOMAX = ',F10.6,' OF FUNCTION HMLF'/)
C
C     IF(ALPHAO .LT.3.) GO TO 12
      IMPROV=1
      IF(IMPROV.EQ.0) GO TO 12
      AL=ALPHAO
      IF(ALPHAO.LE.3.) ALPHAO=3.
      N=2
      IS=1
      IL=IS+N-1
      IF(T.LE.B(IL)) GO TO 2
      IL=25
      IS=IL-N+1
      IF(T.GE.B(IS)) GO TO 2
      IS=1
      IL=IS+N-1
    3 IF((T-B(IS))*(T-B(IL)).LE.0.) GO TO 2
      IS=IL
      IL=IS+N-1
      GO TO 3
```

```
    2 IF(ALPHAO .GT. 3.) GO TO 4
      DO 5 I=IS,IL
      X(I-IS+1)=B(I)
      Y(I-IS+1)=C(I,1)
    5 CONTINUE
      GO TO 6
    4 JS=1
      JL=JS+N-1
      IF(ALPHAO.LE.A(JL)) GO TO 7
      JL=17
      JS=JL-N+1
      IF(ALPHAO.GE.A(JS)) GO TO 7
      JS=1
      JL=JS+N-1
    8 IF((ALPHAO-A(JS))*(ALPHAO-A(JL)).LE.0.) GO TO 7
      JS=JL
      JL=JS+N-1
      GO TO 8
    7 DO 9 J=JS,JL
      U(J-JS+1)=A(J)
    9 CONTINUE
      DO 10 I=IS,IL
      X(I-IS+1)=B(I)
      DO 11 J=JS,JL
      V(J-JS+1)=C(I,J)
   11 CONTINUE
      Y(I-IS+1)=YLAGN(U,V,N,ALPHAO)
   10 CONTINUE
    6 HMLF=YLAGN(X,Y,N,T)
      ALPHAO=AL
      RETURN
   12 IF(ALPHAO.GT. -1.5) GO TO 13
      HMLF=0.549359-0.001148*(T*100.)
     1 +0.001968*(T*100.)**2
      RETURN
   13 N=2
      IS=1
      IL=IS+N-1
      IF(T.LE.G(IL)) GO TO 14
      IL=6
      IS=IL-N+1
      IF(T.GE.G(IS)) GO TO 14
      IS=1
      IL=IS+N-1
   15 IF((T-G(IS))*(T-G(IL)).LE.0.) GO TO 14
      IS=IL
      IL=IS+N-1
      GO TO 15
   14 JS=1
      JL=JS+N-1
   16 IF((ALPHAO-F(JS))*(ALPHAO-F(JL)).LE.0.) GO TO 17
      JS=JL
      JL=JS+N-1
      GO TO 16
   17 DO 18 J=JS,JL
      U(J-JS+1)=F(J)
   18 CONTINUE
      DO 19 I=IS,IL
      X(I-IS+1)=G(I)
      DO 20 J=JS,JL
      V(J-JS+1)=E(I,J)
   20 CONTINUE
      Y(I-IS+1)=YLAGN(U,V,N,ALPHAO)
   19 CONTINUE
      HMLF=YLAGN(X,Y,N,T)
      RETURN
      END
C
C*****************************************************************
C                                                               *
C                        DRAG DATA                              *
C                                                               *
C*****************************************************************
C
```

```
C
      FUNCTION CDFF(T,ALPHAO,HM)
      DIMENSION A(15),X(3),Y(3)
C   DATA A = THICKNESS-CHORD RATIO
      DATA A/0.09,0.1,0.11,0.12,0.13,0.14,0.15,0.16,
     1 0.17,0.19,0.21,0.23,0.25,0.30,0.35/
      TCMIN=0.09
      TCMAX=0.35
      IF(T.LT.TCMIN) WRITE(6,20) T,TCMIN
   20 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' OF FUNCTION CDFF'/)
      IF(T.GT.TCMAX) WRITE(6,31) T,TCMAX
   31 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION CDFF'/)
      IF(T.GT. 0.16) GO TO 1
      IF((T.GT.0.09) .AND. (ALPHAO.GT.5.)) GO TO 1
      CDO=BOF(T,ALPHAO,HM)*COF(T,ALPHAO,HM)
      HMD=HMDF(T,ALPHAO,HM)
      CDS=0.
      H=HM-HMD
      IF(H.GT. 0.) CDS=CDSF(T,ALPHAO,HM,H)
      IF(H.LE.0.4) GO TO 5
    5 CDFF=CDO+CDS
      RETURN
    1 N=2
      IS=1
      IL=IS+N-1
      IF(T.LE.A(IL)) GO TO 2
      IL=15
      IS=IL-N+1
      IF(T.GE.A(IS)) GO TO 2
      IS=1
      IL=IS+N-1
    3 IF((T-A(IS))*(T-A(IL)).LE.0.) GO TO 2
      IS=IL
      IL=IS+N-1
      GO TO 3
    2 DO 4 I=IS,IL
      J=I-IS+1
      X(J)=A(I)
      ALOMIN=3.0
      ALOMAX=11.0
      HMAX=1.0
      IF(ALPHAO.LT.ALOMIN) WRITE(6,40) ALPHAO,ALOMIN
   40 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS LESS',
     &' THAN ALPHAOMIN = ',F10.6,' OF FUNCTION CDFF'/)
      IF(ALPHAO.GT.ALOMAX) WRITE(6,50) ALPHAO,ALOMAX
   50 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS GREATER',
     &' THAN ALPHAOMAX = ',F10.6,' OF FUNCTION CDFF'/)
      IF(HM.GT.HMAX) WRITE(6,65) HM,HMAX
   65 FORMAT(' ',19X,'MACH NO. = ',F10.6,' IS GREATER THAN MACH NO.',
     &'(MAX) = ',F10.6,' OF FUNCTION CDFF'/)
      GO TO (9,10,11,12,13,14,15,16,17,19,21,
     1 23,25,30,35),I
C   DATA 'CD.NO.F': 'CD' = DRAG COEFFICIENT, '.NO.' = THICKNESS-CHORD
C   RATIO
    9 Y(J)=CD9F(T,ALPHAO,HM)
      GO TO 4
   10 Y(J)=CD10F(T,ALPHAO,HM)
      GO TO 4
   11 Y(J)=CD11F(T,ALPHAO,HM)
      GO TO 4
   12 Y(J)=CD12F(T,ALPHAO,HM)
      GO TO 4
   13 Y(J)=CD13F(T,ALPHAO,HM)
      GO TO 4
   14 Y(J)=CD14F(T,ALPHAO,HM)
      GO TO 4
   15 Y(J)=CD15F(T,ALPHAO,HM)
      GO TO 4
   16 Y(J)=CD16F(T,ALPHAO,HM)
      GO TO 4
   17 Y(J)=CD17F(T,ALPHAO,HM)
      GO TO 4
```

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   19 Y(J)=CD19F(T,ALPHAO,HM)
      GO TO 4
   21 Y(J)=CD21F(T,ALPHAO,HM)
      GO TO 4
   23 Y(J)=CD23F(T,ALPHAO,HM)
      GO TO 4
   25 Y(J)=CD25F(T,ALPHAO,HM)
      GO TO 4
   30 Y(J)=CD30F(T,ALPHAO,HM)
      GO TO 4
   35 Y(J)=CD35F(T,ALPHAO,HM)
    4 CONTINUE
      CDFF=YLAGN(X,Y,N,T)
      RETURN
      END
C
      FUNCTION BOF(T,ALPHAO,HM)
C BOF=BO
C ALPHAO=EFFECTIVE ANGLE OF ATTACK
C
      DIMENSION A(51),B(51),X(3),Y(3)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1177, TABLE #6
C   DATA A = ALPHAO = ANGLE OF ATTACK WITH RESPECT TO ZERO LIFT LINE
      DATA A/-2.0,-1.8,-1.6,-1.4,-1.2,-1.0, -0.8,-0.6,-0.4,
     1 -0.2,0.0,0.2,0.4,0.6,0.8,1.0,1.2,1.4,1.6,1.8,2.0,2.2,
     2 2.4,2.6,2.8,3.0,3.2,3.4,3.6,3.8,4.0,4.2,4.4,4.6,4.8,5.0,
     3 5.2,5.4,5.6,5.8,6.0,6.2,6.4,6.6,6.8,7.0,7.2,7.4,7.6,7.8,
     4 8.0/
C
C   DATA B = FACTOR EXPRESSING DEPENDENCE OF LOW-SPEED DRAG ON
C   INCIDENCE (ALPHAO)
      DATA B/1.131,1.114,1.098,1.082,1.067,1.054,1.041,1.030,
     1 1.019,1.009,1.000,0.994,0.987,0.983,0.979,0.976,0.974,
     2 0.973,0.972,0.971,0.972,0.974,0.976,0.978,0.980,0.982,
     3 0.985,0.989,0.994,0.999,1.005,1.012,1.020,1.028,1.037,
     4 1.047,1.057,1.067,1.078,1.090,1.103,1.117,1.132,1.147,
     5 1.162,1.179,1.197,1.216,1.235,1.255,1.276/
      ALOMIN=-2.0
      ALOMAX=8.0
      IF(ALPHAO.LT.ALOMIN) WRITE(6,40) ALPHAO,ALOMIN
   40 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS LESS',
     &' THAN ALPHAOMIN = ',F10.6,' OF FUNCTION BOF'/)
      IF(ALPHAO.GT.ALOMAX) WRITE(6,50) ALPHAO,ALOMAX
   50 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS GREATER',
     &' THAN ALPHAOMAX = ',F10.6,' OF FUNCTION BOF'/)
C
      N=3
      IS=1
      IL=IS+N-1
      IF(ALPHAO.LE.A(IL)) GO TO 1
      IL=51
      IS=IL-N+1
      IF(ALPHAO.GE.A(IS)) GO TO 1
      IS=1
      IL=IS+N-1
    2 IF((ALPHAO-A(IL))*(ALPHAO-A(IS)) .LE. 0.) GO TO 1
      IS=IL
      IL=IS+N-1
      GO TO 2
    1 DO 3 I=IS,IL
      X(I-IS+1)=A(I)
      Y(I-IS+1)=B(I)
    3 CONTINUE
      BOF=YLAGN(X,Y,N,ALPHAO)
      RETURN
      END
C
      FUNCTION COF(T,ALPHAO,HM)
C COF=CO
C T=THICKNESS-CHORD RATIO
C
      DIMENSION A(27),B(27),X(3),Y(3)
C   DATA IS FROM HAINES AND MONAGHAN, P.1177, TABLE #7
C   DATA A = THICKNESS-CHORD RATIO
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```
      DATA A/.03, .035, .04, .045, .05, .055, .06, .065,
     1 .07, .075, .08, .085, .09, .095, .10, .105, .11, .115,
     2 .12, .125, .13, .135, .14, .145, .15, .155, .16/
C   DATA B = FACTOR EXPRESSING DEPENDENCE OF LOW-SPEED DRAG ON
C   THICKNESS
      DATA B/0.00745,0.00753,0.00761,0.00770,0.00780,0.00790,
     1 0.00800,0.00810,0.00820,0.00830,0.00840,0.00851,0.00862,
     2 0.00874,0.00886,0.00898,0.00910,0.00921,0.00932,0.00944,
     3 0.00957,0.00970,0.00983,0.00997,0.01010,0.01025,0.01040/
C
      TCMIN=0.03
      TCMAX=0.16
      IF(T.LT.TCMIN) WRITE(6,20) T,TCMIN
   20 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' OF FUNCTION COF'/)
      IF(T.GT.TCMAX) WRITE(6,30) T,TCMAX
   30 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION COF'/)
      N=2
      IS=1
      IL=IS+N-1
      IF(T.LE.A(IL)) GO TO 1
      IL=27
      IS=IL-N+1
      IF(T.GE.A(IS)) GO TO 1
      IS=1
      IL=IS+N-1
    2 IF((T-A(IL))*(T-A(IS)) .LE. 0.) GO TO 1
      IS=IL
      IL=IS+N-1
      GO TO 2
    1 DO 3 I=IS,IL
      X(I-IS+1)=A(I)
      Y(I-IS+1)=B(I)
    3 CONTINUE
      COF=YLAGN(X,Y,N,T)
      RETURN
      END
C
      FUNCTION CDSF(T,ALPHAO,HM,H)
C CDSF=CDS
C H=M-MD
C
      DIMENSION A(40),B(40),X(3),Y(3)
C   DATA IS FROM MACDOUGALL, P. 1033, TABLE #2
C   DATA A = (M-MD), WHERE M=LOCAL MACH NO., MD= CRITICAL MACH NO.
C   FOR DRAG AT WHICH DRAG DEPARTS FROM ITS LOW-SPEED VALUE
      DATA A/0.01,0.02,0.03,0.04,0.05,0.06,0.07,0.08,0.09,
     1 0.10,0.11,0.12,0.13,0.14,0.15,0.16,0.17,0.18,0.19,
     2 0.20,0.21,0.22,0.23,0.24,0.25,0.26,0.27,0.28,0.29,
     3 0.30,0.31,0.32,0.33,0.34,0.35,0.36,0.37,0.38,0.39,
     4 0.40/
C
C   DATA B = DRAG COEFFICIENT
      DATA B/0.0001,0.0009,0.0022,0.0040,0.0063,0.0091,0.0122,
     1 0.0154,0.0187,0.0221,0.0255,0.0288,0.0322,0.0356,0.0389,
     2 0.0423,0.0456,0.0490,0.0524,0.0557,0.0591,0.0625,0.0658,
     3 0.0692,0.0726,0.0759,0.0793,0.0826,0.0860,0.0894,0.0927,
     4 0.0961,0.0995,0.1028,0.1062,0.1096,0.1129,0.1163,0.1196,
     5 0.1230/
C
      HMIN=0.01
      HMAX=0.40
      IF(H.LT.HMIN) WRITE(6,10) H,HMIN
  10  FORMAT(' ',19X,'H = M-MD = ',F10.6,' IS LESS THAN HMIN = ',
     &F10.6,' OF FUNCTION CDSF'/)
      IF(H.GT.HMAX) WRITE(6,20) H,HMAX
  20  FORMAT(' ',19X,'H = M-MD = ',F10.6,' IS GREATER THAN HMAX = ',
     &F10.6,' OF FUNCTION CDSF'/)
      N=2
      IS=1
      IL=IS+N-1
      IF(HM.LE.A(IL)) GO TO 1
      IL=40
```

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      IS=IL-N+1
      IF(HM.GE.A(IS)) GO TO 1
      IS=1
      IL=IS+N-1
    2 IF((HM-A(IL))*(HM-A(IS)) .LE. 0.) GO TO 1
      IS=IL
      IL=IS+N-1
      GO TO 2
    1 DO 3 I=IS,IL
      X(I-IS+1)=A(I)
      Y(I-IS+1)=B(I)
    3 CONTINUE
      CDSF=YLAGN(X,Y,N,H)
      RETURN
      END
C
      FUNCTION HMDF(T,ALPHAO,HM)
C HMDF=MD
C ALPHAO=EFFECTIVE ANGLE OF ATTACK
C
C T=THICKNESS-CHORD RATIO
C
      DIMENSION A(18),B(13),C(13,18),U(3),V(3),X(3),Y(3)
C
C   DATA IS FROM MACDOUGALL, PP.1032-33, TABLES #1A&B
C   DATA A = ALPHAO = ANGLE OF ATTACK WITH RESPECT TO ZERO LIFT LINE
      DATA A/-1.5,-1.0,-0.5,0.,0.5,1.0,1.5,2.0,2.5,3.0,
     1 3.5,4.0,4.5,5.0,5.5,6.0,6.5,7.0/
C   DATA B = THICKNESS-CHORD RATIO
      DATA B/.045, .05, .06, .07, .08, .09, .10, .11,
     1 .12, .13, .14, .15, .16/
C   DATA C = CRITICAL MACH NO. FOR DRAG AT WHICH THE DRAG DEPARTS
C   FROM ITS LOW-SPEED VALUE
      DATA (C(I,1),I=1,13)/
     1 0.718,0.705,0.674,0.627,
     1  0.620,0.5915,0.560,0.5255,0.5015,0.4715,
     1 0.4435,0.412,0.378/
      DATA (C(I,2),I=1,13)/
     2 0.763,0.749,0.718,0.675,
     2 0.6575,0.629,0.599,0.5705,0.5425,0.514,0.487,
     2 0.4575,0.4265/
      DATA (C(I,3),I=1,13)/
     3 0.800,0.785,0.755,0.715,
     3 0.690,0.6625,0.634,0.6065,0.5795,
     3 0.5525,0.5265,0.499,0.471/
      DATA (C(I,4),I=1,13)/
     4 0.820,0.811,0.782,0.750,0.728,0.709,0.691,0.674,
     4 0.658,0.643,0.629,0.614,0.600/
      DATA (C(I,5),I=1,13)/
     5 0.810,0.817,0.800,0.774,0.750,0.728,0.709,0.690,
     5 0.672,0.656,0.640,0.625,0.613/
      DATA (C(I,6),I=1,13)/
     6 0.787,0.805,0.808,0.790,0.768,0.746,0.725,0.705,
     6 0.685,0.667,0.651,0.637,0.625/
      DATA (C(I,7),I=1,13)/
     7 0.762,0.785,0.806,0.799,0.776,0.755,0.735,0.715,0.696,
     7 0.678,0.661,0.647,0.637/
      DATA (C(I,8),I=1,13)/
     8 0.735,0.761,0.796,0.800,0.774,0.752,0.732,0.715,
     8 0.698,0.682,0.667,0.655,0.646/
      DATA (C(I,9),I=1,13)/
     9 0.707,0.735,0.779,0.795,0.766,0.741,0.716,0.699,0.684,
     9 0.671,0.662,0.654,0.648/
      DATA (C(I,10),I=1,13)/
     $ 0.680,0.707,0.756,0.781,0.752,0.724,0.697,0.681,
     $ 0.667,0.657,0.650,0.643,0.637/
      DATA (C(I,11),I=1,13)/
     1 0.651,0.680,0.731,0.761,0.733,0.705,0.678,0.662,0.648,
     1 0.639,0.632,0.626,0.621/
      DATA (C(I,12),I=1,13)/
     2 0.621,0.650,0.702,0.737,0.713,0.684,0.660,0.644,
     2 0.630,0.620,0.611,0.605,0.600/
      DATA (C(I,13),I=1,13)/
     3 0.593,0.620,0.671,0.708,0.690,0.672,0.642,0.626,0.612,
```

```
     3 0.602,0.593,0.586,0.580/
      DATA (C(I,14),I=1,13)/
     4 0.565,0.591,0.641,0.679,0.663,0.641,0.625,0.610,
     4 0.597,0.587,0.580,0.574,0.570/
      DATA (C(I,15),I=1,13)/
     5 0.537,0.563, 0.611, 0.649,
     5 0.6605,0.6715,0.6825,0.6935,
     5 0.7055,0.7185,0.734,0.7495,0.7665/
      DATA (C(I,16),I=1,13)/
     6 0.509,0.535, 0.583, 0.620,
     6 0.6325,0.646,0.6595,0.671,0.6835,
     6 0.6965,0.713,0.729,0.747/
      DATA (C(I,17),I=1,13)/
     7 0.481,0.507, 0.556, 0.590,
     7 0.601,0.614,0.627,0.636,0.646,
     7 0.656,0.6705,0.684,0.700/
      DATA (C(I,18),I=1,13)/
     8 0.453,0.479, 0.529, 0.564,
     8 0.5735,0.588,0.6025,0.611,0.6205,
     8 0.6295,0.644,0.657,0.673/
      TCMIN=0.045
      TCMAX=0.16
      ALOMIN=-1.5
      ALOMAX=7.0
      IF(T.LT.TCMIN) WRITE(6,20) T,TCMIN
   20 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' OF FUNCTION HMDF'/)
      IF(T.GT.TCMAX) WRITE(6,30) T,TCMAX
   30 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION HMDF'/)
      IF(ALPHAO.LT.ALOMIN) WRITE(6,40) ALPHAO,ALOMIN
   40 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,' IS LESS',
     &' THAN ALPHAOMIN = ',F10.6,' OF FUNCTION HMDF'/)
      IF(ALPHAO.GT.ALOMAX) WRITE(6,50) ALPHAO,ALOMAX
   50 FORMAT(' ',19X,'ALPHAO = ALPHA-ALPHLO = ',F10.6,'IS GREATER',
     &' THAN ALPHAOMAX = ',F10.6,' OF FUNCTION HMDF'/)
      N=2
      IS=1
      IL=IS+N-1
      IF(T.LE.B(IL)) GO TO 1
      IL=13
      IS=IL-N+1
      IF(T.GE.B(IS)) GO TO 1
      IS=1
      IL=IS+N-1
    2 IF((T-B(IS))*(T-B(IL)) .LE.0.) GO TO 1
      IS=IL
      IL=IS+N-1
      GO TO 2
    1 JS=1
      JL=JS+N-1
      IF(ALPHAO.LE.A(JL)) GO TO 3
      JL=18
      JS=JL-N+1
      IF(ALPHAO.GE.A(JS)) GO TO 3
      JS=1
      JL=JS+N-1
    4 IF((ALPHAO-A(JS))*(ALPHAO-A(JL)).LE.0.) GO TO 3
      JS=JL
      JL=JS+N-1
      GO TO 4
    3 DO 5 J=JS,JL
      U(J-JS+1)=A(J)
    5 CONTINUE
      DO 6 I=IS,IL
      X(I-IS+1)=B(I)
      DO 7 J=JS,JL
      V(J-JS+1)=C(I,J)
    7 CONTINUE
      Y(I-IS+1)=YLAGN(U,V,N,ALPHAO)
    6 CONTINUE
      HMDF=YLAGN(X,Y,N,T)
      RETURN
      END
```

```
C
C
C
      FUNCTION CD9F(T,ALPHAO,HM)
      DIMENSION AO(4),HM5(7),HM6(7),HM7(7),HM8(7),
     $ CD5(7),CD6(7),CD7(7),CD8(7)
      DIMENSION HM3(1),HM4(1),HM9(1),HM10(1),HM11(1),
     1 CD3(1),CD4(1),CD9(1),CD10(1),CD11(1)
C    DATA IS FROM MACDOUGALL, P. 1036, FIG. 5
C    DATA AO = ALPHAO = ALGLE OF ATTACK WITH RESPECT TO ZERO LIFT LINE
C    DATA 'HM.NO.': 'HM' = MACH NO., '.NO.' = MACH NO.*10
C    DATA 'CD.NO.': 'CD' = DRAG COEFFICIENT, '.NO.' = MACH NO.*10
      DATA AO/5.,6.,7.,8./
      DATA HM5/0.6545, 0.66364, 0.67273, 0.68182, 0.7,
     $ 0.8, 0.9/
      DATA CD5/0.00909, 0.00982, 0.01091, 0.01327, 0.01818,
     $ 0.05018, 0.08545/
      DATA HM6/0.62727, 0.63636, 0.64545, 0.65455, 0.7,
     $ 0.8, 0.9/
      DATA CD6/0.00945, 0.01, 0.01091, 0.01273, 0.02727,
     $ 0.06182, 0.1/
      DATA HM7/0.60909, 0.61818, 0.62727, 0.63636,
     $ 0.7, 0.8, 0.9/
      DATA CD7/0.01073, 0.01109, 0.01273, 0.01455,
     $ 0.03655, 0.07636, 0.12273/
      DATA HM8/0.6, 0.60909, 0.61818, 0.62727, 0.7,
     $ 0.8, 0.9/
      DATA CD8/0.01273, 0.01455, 0.01636, 0.01818,
     $ 0.04682, 0.09455, 0.14764/
      CD9F=CDTHKF(T,ALPHAO,HM,AO,4,
     1 HM5,HM6,HM7,HM8,HM3,HM4,HM9,HM10,HM11,
     2 CD5,CD6,CD7,CD8,CD3,CD4,CD9,CD10,CD11,
     3 7,7,7,7,0,0,0,0,0)
      RETURN
      END
C
      FUNCTION CD10F(T,ALPHAO,HM)
      DIMENSION AO(7),HM5(10),CD5(10),HM6(10),CD6(10),
     1 HM7(10),CD7(10),HM8(10),CD8(10),HM9(10),CD9(10),
     2 HM10(12),CD10(12),HM11(12),CD11(12)
      DIMENSION HM3(1),HM4(1),CD3(1),CD4(1)
C    DATA IS FROM MACDOUGALL, P. 1036, FIG. 6
      DATA AO/5.,6.,7.,8.,9.,10.,11./
      DATA HM5/.62, .63, .64, .65, .66, .67, .7, .8, .9, 1./
      DATA CD5/.0086, .009, .01, .0109, .013, .0158, .024,
     1 .058, .0906, .124/
      DATA HM6/.6, .61, .62, .63, .64, .65, .7,.8,.9,1./
      DATA CD6/.0094, .01, .0108, .012, .0138, .016, .03,
     1 .065, .105, .149/
      DATA HM7/.58, .59, .60, .61, .62, .63, .7, .8, .9, 1./
      DATA CD7/.01, .0104, .011, .0121, .0141, .018, .04,
     1 .078, .128, .184/
      DATA HM8/.57, .58, .59, .60, .61, .62, .7, .8, .9, .97/
      DATA CD8/.0112, .012, .0136, .016, .019, .0222, .05,
     1 .098, .154, .2/
      DATA HM9/ .54, .55, .56, .57, .58, .59, .7, .8, .9,.91/
      DATA CD9/.012, .0128, .0138, .016, .018, .0216, .067,
     1 .1224, .192, .2/
      DATA HM10/.52, .53, .54, .55, .56, .57, .58, .59, .6, .7,
     1 .8, .86/
      DATA CD10/.014,.0142,.016,.017,.0198,.022,.026,
     1 .03, .034, .086, .151, .2/
      DATA HM11/.5, .51, .52, .53, .54, .55, .56, .57, .6, .7,
     1 .8, .82/
      DATA CD11/.016, .01618, .0164, .0176, .02, .023, .0262,
     1 .03, .045, .103, .178, .2/
      CD10F=CDTHKF(T,ALPHAO,HM,AO,7,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
     2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
     3 10,10,10,10,10,12,12,0,0)
      RETURN
      END
C
C
```

```
      FUNCTION CD11F(T,ALPHAO,HM)
      DIMENSION AO(6),HM5(9),CD5(9),HM6(9),CD6(9),
     1 HM7(9),CD7(9),HM8(9),CD8(9),HM9(11),CD9(11),
     2 HM10(9),CD10(9)
      DIMENSION HM3(1),HM4(1),HM11(1),CD3(1),CD4(1),
     1 CD11(1)
C    DATA IS FROM MACDOUGALL,P. 1037, FIG. 7
      DATA AO/5.,6.,7.,8.,9.,10./
      DATA HM5/.62727, .63636, .64545,.65455, .66364, .67273,
     1 .7, .8, .9/
      DATA CD5/.00903, .01, .01109, .01291, .01545, .01855,
     1 .02727, .06182, .09818/
      DATA HM6/.6, .60909, .61818, .62727, .63636, .64545,
     1 .7, .8, .9/
      DATA CD6/.00964, .01, .01091, .01209, .01455, .01636,
     1 .03327, .06909, .11018/
      DATA HM7/.57273,.58182, .59091, .6, .60909, .61818,
     1 .7, .8, .9/
      DATA CD7/.01036, .01064, .011, .01182, .01345, .01545,
     1 .04364, .08545, .134/
      DATA HM8/.56364, .57273, .58182, .59091, .6, .60909, .7,
     2 .8, .9/
      DATA CD8/.01091, .01136, .01273, .01455, .01636, .01909,
     1 .05455, .10455, .16273/
      DATA HM9/.53636, .54545, .55454, .56364, .57273, .58182,
     1 .6, .64545, .7,.8,.88182/
      DATA CD9/.01182, .01218, .01273, .01427, .01636, .01864,
     1 .02491, .03291, .07091, .12909, .18/
      DATA HM10/.52727, .53636, .54545, .55454, .56364,.6,
     1 .64545, .7, .8/
      DATA CD10/.01273, .01309, .01455, .01636, .02, .0360,
     1 .06, .08909, .15636/
      CD11F=CDTHKF(T,ALPHAO,HM,AO,6,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
     2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
     3 9,9,9,9,11,9,0,0,0)
      RETURN
      END
C
      FUNCTION CD12F(T,ALPHAO,HM)
      DIMENSION  AO(6),HM5(10),CD5(10),HM6(11),CD6(11),
     1 HM7(11),CD7(11),HM8(11),CD8(11),HM9(11),CD9(11),
     2 HM10(12),CD10(12)
      DIMENSION HM3(1),HM4(1),HM11(1),CD3(1),CD4(1),CD11(1)
C    DATA IS FROM MACDOUGAL, P. 1037, FIG. 8
      DATA AO/5.,6.,7.,8.,9.,10./
      DATA HM5/.59, .6, .61, .62, .63, .64, .65, .7, .8, .9/
      DATA CD5/.0099, .01020, .01140, .013, .015, .017, .0198,
     1 .034, .066, .10/
      DATA HM6/.57, .58, .59, .6, .61, .62, .63, .64, .7, .8, .9/
      DATA CD6/.0102,.011, .012, .013, .0147, .0164, .018, .02,
     1 .038, .074, .1150/
      DATA HM7/.55, .56, .57, .58, .59, .60, .61, .65, .7, .8, .9/
      DATA CD7/.0112, .0114, .012, .0136, .0156, .0169, .019, .03,
     1 .048, .0886, .14/
      DATA HM8/.54, .55, .56, .57, .58, .59, .6, .65, .7, .8, .9/
      DATA CD8/.012, .0122, .014, .015, .0179, .02, .0221, .04, .06,
     1 .11, .168/
      DATA HM9/.52, .53, .54, .55, .56, .57, .6, .65, .7, .8, .9/
      DATA CD9/.012, .013, .014, .016, .018, .02, .03, .05, .074,
     1 .1302, .20/
      DATA HM10/.51, .52, .53, .54, .55, .56, .57, .6, .65, .7,.8,.85/
      DATA CD10/.014, .0144, .016, .018, .02, .0237, .026, .04, .0638,
     1 .092, .158, .20/
      CD12F=CDTHKF(T,ALPHAO,HM,AO,6,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
     2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
     3 10,11,11,11,11,12,0,0,0)
      RETURN
      END
C
      FUNCTION CD13F(T,ALPHAO,HM)
      DIMENSION AO(6),HM5(5),CD5(5),HM6(8),CD6(8),HM7(8),CD7(8),
     1 HM8(9),CD8(9),HM9(9),CD9(9),HM10(8),CD10(8)
```

```
      DIMENSION HM3(1),HM4(1),HM11(1),CD3(1),CD4(1),CD11(1)
C   DATA IS FROM MACDOUGALL, P.1038, FIG. 9
      DATA AO/5., 6., 7., 8., 9., 10./
      DATA HM5/.58, .59, .6, .7, .9/
      DATA CD5/.01, .0102, .011, .038, .1027/
      DATA HM6/.57, .58, .59, .6, .63, .7, .8, .9/
      DATA CD6/.0103, .011, .012, .014, .02, .042, .078, .12/
      DATA HM7/.56, .57, .58, .59, .6, .7, .8, .9/
      DATA CD7/.0112, .012, .0134, .0154, .018, .05, .096, .146/
      DATA HM8/.54, .55, .56, .57, .58, .6, .7, .8, .9/
      DATA CD8/.012, .013, .014, .016, .018, .0254, .064, .114,.174/
      DATA HM9/.52, .53, .54, .55, .56, .6, .7, .8, .9/
      DATA CD9/.0132, .0139, .0142, .016, .018, .034, .078,
     1 .1362, .2/
      DATA HM10/.51, .52, .53, .54, .6, .7, .8, .845/
      DATA CD10/.014, .01416, .016, .02, .042, .092, .1622, .2/
      CD13F=CDTHKF(T,ALPHAO,HM,AO,6,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
     2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
     3 5,8,8,9,9,8,0,0,0)
      RETURN
      END
C
C
      FUNCTION CD14F(T,ALPHAO,HM)
      DIMENSION AO(6),HM5(7),CD5(7),HM6(8),CD6(8),HM7(9),CD7(9),
     1 HM8(9),CD8(9),HM9(9),CD9(9),HM10(8),CD10(8)
      DIMENSION HM3(1),HM4(1),HM11(1),CD3(1),CD4(1),CD11(1)
C   DATA IS FROM MACDOUGALL, P. 1038, FIG. 10
      DATA AO/5.,6.,7.,8.,9.,10./
      DATA HM5/.58, .59, .6, .61, .7, .8, .9/
      DATA CD5/.01, .01018, .0112, .014, .04, .074, .1079/
      DATA HM6/.57, .58, .59, .6, .61, .7, .8, .9/
      DATA CD6/.0108, .012, .014, .0156, .018, .047, .084, .128/
      DATA HM7/.55, .56, .57, .58, .59, .6, .7, .8, .9/
      DATA CD7/.0114, .012, .0132, .0156, .018, .02, .058, .102,
     1 .1526/
      DATA HM8/.53, .54, .55, .56, .57, .6, .7, .8, .9/
      DATA CD8/.012, .0128, .014, .016, .02, .0286, .07, .12, .1822/
      DATA HM9/.51, .52, .53, .54, .55, .6, .7, .8, .88/
      DATA CD9/.0136, .0138, .0144, .016, .02, .038, .082, .1424, .2/
      DATA HM10/.5, .51, .52, .53, .6, .7, .8, .84/
      DATA CD10/.014, .0144, .016, .018, .048, .098, .166, .2/
      CD14F=CDTHKF(T,ALPHAO,HM,AO,6,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
     2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
     3 7,8,9,9,9,8,0,0,0)
      RETURN
      END
C
C
      FUNCTION CD15F(T,ALPHAO,HM)
      DIMENSION AO(6),HM5(7),CD5(7),HM6(9),CD6(9),HM7(10),CD7(10),
     1 HM8(11),CD8(11),HM9(9),CD9(9),HM10(10),CD10(10)
      DIMENSION HM3(1),HM4(1),HM11(1),CD3(1),CD4(1),CD11(1)
C   DATA IS FROM MACDOUGALL, P.1039, FIG. 11
      DATA AO/5., 6., 7., 8., 9., 10./
      DATA HM5/.57, .58, .59, .6, .7, .8, .9/
      DATA CD5/.01, .0104, .0114, .013, .042, .076, .11/
      DATA HM6/.55, .56, .57, .58, .59, .6, .7, .8, .9/
      DATA CD6/.0104, .0108, .012, .014, .016, .018, .05, .09, .1334/
      DATA HM7/.53, .54, .55, .56, .57, .58, .6, .7, .8, .9/
      DATA CD7/.0113, .012, .0124, .014, .016, .02, .025, .062,
     1 .106, .16/
      DATA HM8/.51, .52, .53, .54, .55, .56, .57, .6, .7, .8, .9/
      DATA CD8/.012, .0122, .014, .015, .0172, .02, .022, .032,
     1 .07378, .126, .19/
      DATA HM9/.5, .51, .52, .53, .54, .6, .7, .8, .87/
      DATA CD9/.0134, .0136, .014, .016, .02, .04, .086, .148, .2/
      DATA HM10/.5, .51, .52, .53, .54, .55, .6, .7, .8, .835/
      DATA CD10/.0147, .0155, .017, .02, .024, .028, .0496, .1032,
     1 .172, .2/
      CD15F=CDTHKF(T,ALPHAO,HM,AO,6,
     1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
```

```
      2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
      3 7,9,10,11,9,10,0,0,0)
        RETURN
        END
C
        FUNCTION CD16F(T,ALPHAO,HM)
        DIMENSION AO(7),HM5(6),CD5(6),HM6(9),CD6(9),HM7(10),CD7(10),
      1 HM8(11),CD8(11),HM9(10),CD9(10),HM10(11),CD10(11),HM11(11),
      2 CD11(11)
        DIMENSION HM3(1),HM4(1),CD3(1),CD4(1)
C     DATA IS FROM HAINES AND MONAGHAN, P. 1187, FIG. 8
        DATA AO/5., 6., 7., 8., 9., 10., 11./
        DATA HM5/.55, .56667, .5833, .6, .65, .9/
        DATA CD5/.01083, .01233, .015, .01833, .03333, .118/
        DATA HM6/.51667, .53333, .55, .56667, .6, .65, .7, .8, .9/
        DATA CD6/.01167, .01267, .015, .01833, .02667, .0425, .06,
      1 .10167, .14783/
        DATA HM7/.4833, .5, .51667, .53333, .55, .6, .65, .7, .8, .9/
        DATA CD7/.01217, .01267, .015, .01742, .02167, .03333, .05167,
      1 .07033, .11833, .178/
        DATA HM8/.46667, .48333, .5, .51667, .55, .6, .65, .7, .75,
      1 .8, .9/
        DATA CD8/.01283, .013333, .01575, .01942, .02708, .04333, .06,
      1 .08267, .105, .13667, .20192/
        DATA HM9/.46667, .48333, .5, .5333, .55, .6, .7, .75, .8,
      1 .89417/
        DATA CD9/.01333, .01583, .01933, .02667, .0315, .04833, .095,
      1 .12167, .15733, .23/
        DATA HM10/.4625, .48333, .5, .525, .55, .6, .65, .7, .75,
      1 .8, .85833/
        DATA CD10/.015, .01867, .02217, .03, .03708, .05667, .0815,
      1 .11, .14217, .18133, .23/
        DATA HM11/.45, .45833, .46667, .5, .525, .6, .65, .7, .75,
      1 .8, .81667/
        DATA CD11/.01667, .01717, .01917, .02667, .03667, .06617,
      1 .09367, .12633, .165, .212, .23/
        CD16F=CDTHKF(T,ALPHAO,HM,AO,7,
      1 HM5,HM6,HM7,HM8,HM9,HM10,HM11,HM3,HM4,
      2 CD5,CD6,CD7,CD8,CD9,CD10,CD11,CD3,CD4,
      3 6,9,10,11,10,11,11,0,0)
        RETURN
        END
C
        FUNCTION CD17F(T,ALPHAO,HM)
        DIMENSION AO(9),HM3(4),CD3(4),HM4(7),CD4(7),CD5(6),HM5(6),
      1 HM6(8),CD6(8),HM7(8),CD7(8),HM8(8),CD8(8),HM9(11),CD9(11),
      2 HM10(9),CD10(9),HM11(10),CD11(10)
C     DATA IS FROM HAINES AND MONAGHAN, P. 1188, FIG. 9
        DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
        DATA HM3/.64, .65, .7, .8/
        DATA CD3/.01, .011, .027, .068/
        DATA HM4/.59, .6, .62, .63, .65, .7, .8/
        DATA CD4/.01, .011, .013, .015, .021, .0275, .08/
        DATA HM5/.57, .58, .6, .65, .7, .8/
        DATA CD5/.01125, .012, .01545, .0325, .0525, .095/
        DATA HM6/.54, .55, .56, .57, .58, .6, .61, .8/
        DATA CD6/.01225, .0125, .015, .016, .0195, .025, .02975, .11/
        DATA HM7/.52, .53, .54, .55, .57, .6, .75, .8/
        DATA CD7/.014, .015, .0154, .018, .025, .0355, .1035, .130/
        DATA HM8/.5, .51, .52, .53, .55, .6, .7, .8/
        DATA CD8/.015, .016, .017, .02, .025,.044, .095, .1475/
        DATA HM9/.49, .5, .51, .53, .55, .57, .6, .65, .7, .75, .8/
        DATA CD9/.01625, .0175, .02, .025, .0315, .04, .052, .075,
      1 .1025, .13375, .1675/
        DATA HM10/.47, .48, .5, .52, .55, .6, .65, .7, .8/
        DATA CD10/.0175, .01875, .022, .0275, .03875, .06, .086, .1185,
      1 .19/
        DATA HM11/.46, .47, .5, .52, .55, .6, .65, .7, .75, .8/
        DATA CD11/.01925, .02, .026, .034, .045, .07, .1, .135, .1965,
      1 .2175/
        CD17F=CDTHKF(T,ALPHAO,HM,AO,9,
      1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
      2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
      3 4,7,6,8,8,8,11,9,10)
```

```
      RETURN
      END
C
C
      FUNCTION CD19F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(6),CD3(6),HM4(6),CD4(6),HM5(5),CD5(5),
     1 HM6(7),CD6(7),HM7(7),CD7(7),HM8(8),CD8(8),HM9(9),CD9(9),
     2 HM10(9),CD10(9),HM11(9),CD11(9)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1188, FIG. 10
      DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.59, .61, .63, .65, .67, .8/
      DATA CD3/.01, .0105, .01425, .02, .0275, .0925/
      DATA HM4/.56, .59, .61, .63, .65, .8/
      DATA CD4/.0105, .012, .01575, .02175, .03, .1025/
      DATA HM5/.54, .56, .59, .61, .8/
      DATA CD5/.0125, .014, .0175, .0245, .11625/
      DATA HM6/.51, .54, .56, .59,  .61, .75, .8/
      DATA CD6/.014, .015, .0175, .025, .034, .1085, .1355/
      DATA HM7/.49, .51, .54, .56, .59, .75, .8/
      DATA CD7/.015, .0154, .02, .025, .035, .124, .1515/
      DATA HM8/.47, .49, .51, .54, .56, .59, .75, .8/
      DATA CD8/.016, .0175, .02, .025, .0315, .045, .1385, .171/
      DATA HM9/.45, .47, .49, .51, .54, .56, .59,.75, .8/
      DATA CD9/.0175, .01925, .02025, .025, .032, .04, .055, .1505,
     1 .1875/
      DATA HM10/.45, .47, .49, .51, .54, .56, .59, .75, .8/
      DATA CD10/.01925, .02125, .025, .03, .04, .049, .065, .17,
     1 .2085/
      DATA HM11/.45, .47, .49, .51, .54, .56, .59, .75, .8/
      DATA CD11/.02, .02475, .0295, .035, .0465, .059, .0754, .19125,
     1 .236/
      CD19F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 6,6,5,7,7,8,9,9,9)
      RETURN
      END
C
      FUNCTION CD21F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(6),CD3(6),HM4(6),CD4(6),HM5(6),CD5(6),
     1 HM6(7),CD6(7), HM7(6),CD7(6),HM8(7),CD8(7),HM9(7),CD9(7),
     2 HM10(6),CD10(6),HM11(7),CD11(7)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1189, FIG. 11
      DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.57, .6, .62, .65, .67, .8/
      DATA CD3/.01425, .015, .018, .026, .035, .11/
      DATA HM4/.56, .58, .6, .64, .72, .8/
      DATA CD4/.01425, .0155, .01925, .0305, .075, .125/
      DATA HM5/.52, .55, .58, .6, .65, .8/
      DATA CD5/.01425, .015, .02, .025, .045, .1405/
      DATA HM6/.5, .55, .575, .6, .65, .7, .8/
      DATA CD6/.015, .02, .025, .0335, .057, .0895, .1625/
      DATA HM7/.47, .5, .55, .6, .65, .8/
      DATA CD7/.016, .018, .0255, .0425, .0705, .18/
      DATA HM8/.45, .48, .5, .55, .6, .65, .8/
      DATA CD8/.0175, .01975, .021, .0345, .0515, .084, .195/
      DATA HM9/.45, .48, .52, .57, .62, .7, .8/
      DATA CD9/.0195, .022, .03045,.05, .075, .1305, .214/
      DATA HM10/.44, .48, .5, .55, .65, .8/
      DATA CD10/.02, .025, .03, .0505, .11, .231/
      DATA HM11/.43, .45, .48, .55, .61, .71, .8/
      DATA CD11/.022, .0235, .03, .06, .1, .175, .26/
      CD21F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 6,6,6,7,6,7,7,6,7)
      RETURN
      END
C
      FUNCTION CD23F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(9),CD3(9),HM4(8),CD4(8),HM5(9),CD5(9),
     1 HM6(9),CD6(9),HM7(9),CD7(9),HM8(9),CD8(9),HM9(9),CD9(9),
     2 HM10(9),CD10(9),HM11(9),CD11(9)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1189, FIG. 12
```

```
      DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.55, .58, .6, .63, .65, .68, .7, .75, .8/
      DATA CD3/.013, .015, .017, .025, .03075, .045, .056, .09,.129/
      DATA HM4/.53, .56, .58, .6, .63, .67, .71, .8/
      DATA CD4/.013, .015, .0175, .02075, .03, .05, .075, .145/
      DATA HM5/.48, .52, .55, .58, .6, .64, .69, .75, .8/
      DATA CD5/.013, .015, .0165, .2, .02545, .039, .075, .12, .161/
      DATA HM6/.49, .52, .55, .59, .6, .63, .67, .735, .8/
      DATA CD6/.015, .017, .0204, .03, .034, .0495, .075, .125, .181/
      DATA HM7/.4, .45, .5, .54, .58, .6, .66, .71, .8/
      DATA CD7/.0155, .016, .02, .025, .035, .043, .08, .12, .205/
      DATA HM8/.4, .45, .5, .53, .55, .58, .6, .71, .8/
      DATA CD8/.016, .0175, .02425, .03, .035, .045, .0535, .135, .222/
      DATA HM9/.4, .45, .485, .55, .57, .6, .65, .71, .75/
      DATA CD9/.0175, .02, .025, .043, .0505, .06625, .10075, .152,
     1 .192/
      DATA HM10/.4, .42, .45, .5, .54, .585, .63, .69, .73/
      DATA CD10/.0195, .02, .02325, .035, .05, .075, .105, .155, .19/
      DATA HM11/.4, .43, .47, .5, .55, .58, .64, .72, .8/
      DATA CD11/.0204, .025, .03, .0445, .07, .09, .135, .205, .281/
      CD23F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 9,8,9,9,9,9,9,9,9)
      RETURN
      END
C
      FUNCTION CD25F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(8),CD3(8),HM4(9),CD4(9),HM5(8),CD5(8),
     1 HM6(8),CD6(8),HM7(9),CD7(9),HM8(9),CD8(9),HM9(9),CD9(9),
     2 HM10(8),CD10(8),HM11(7),CD11(7)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1190, FIG. 13
      DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.55,.58, .6, .624, .65, .68, .75, .8/
      DATA CD3/.015, .0165, .02, .025, .0325, .05, .1, .1454/
      DATA HM4/.52, .55, .58, .6, .64, .65, .68, .76, .8/
      DATA CD4/.015, .0155, .02, .02425, .0355, .04, .06, .125, .166/
      DATA HM5/.5, .56, .59, .62, .65, .71, .75, .8/
      DATA CD5/.015, .02, .025, .035, .05, .095, .135, .19/
      DATA HM6/.46, .51, .55, .6, .63, .67, .725, .8/
      DATA CD6/.015, .0175, .0235, .035, .05, .0775, .125, .2125/
      DATA HM7/.4, .45, .5, .55, .59, .63, .68, .76, .8/
      DATA CD7/.0155, .017, .0205, .03, .04, .06, .1, .18, .233/
      DATA HM8/.4, .45, .5, .55, .59, .61, .65, .74, .8/
      DATA CD8/.0175, .02, .025, .035, .05, .06, .0825, .18, .25/
      DATA HM9/.4, .43, .47, .5, .55, .58, .61, .67, .8/
      DATA CD9/.0195, .02, .025, .03, .045, .0555, .075, .126, .2675/
      DATA HM10/.4, .44, .49, .53, .58, .65, .73, .8/
      DATA CD10/.02, .025, .035, .04975, .076, .132, .207, .285/
      DATA HM11/.4,.46, .5, .55, .62, .71, .8/
      DATA CD11/.021, .035, .05, .078, .13, .215, .305/
      CD25F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 8,9,8,8,9,9,9,8,7)
      RETURN
      END
C
      FUNCTION CD30F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(9),CD3(9),HM4(8),CD4(8),HM5(8),CD5(8),
     1 HM6(9),CD6(9),HM7(8),CD7(8),HM8(10),CD8(10),HM9(8),CD9(8),
     2 HM10(8),CD10(8),HM11(7),CD11(7)
C   DATA IS FROM HAINES AND MONAGHAN, P.1190, FIG. 14
      DATA AO/3., 4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.4, .55, .585, .63, .65, .69, .735, .76, .78/
      DATA CD3/.015, .018, .02, .03, .037, .06, .1, .13, .16/
      DATA HM4/.4, .53, .59, .64, .68, .72, .757, .8/
      DATA CD4/.015, .018, .024, .04, .065, .102, .15, .22/
      DATA HM5/.4, .51, .57, .62, .65, .7, .74, .8/
      DATA CD5/.015, .018, .025, .04, .055, .1, .15, .25/
      DATA HM6/.4, .5, .55, .6, .64, .66, .7, .78, .8/
      DATA CD6/.016, .02, .025, .0395, .06, .077, .12, .24, .275/
      DATA HM7/.46, .53, .58, .62, .65, .7, .74, .8/
      DATA CD7/.02, .03, .04, .059, .081, .14, .199, .3/
```

```
      DATA HM8/.4, .45, .5, .55, .6, .68, .665, .7, .75, .8/
      DATA CD8/.02, .021, .03, .041, .061, .082, .12, .165, .24, .33/
      DATA HM9/.4, .45, .5, .55, .6, .65, .72, .8/
      DATA CD9/.02, .025, .033, .05, .08, .133, .22, .35/
       DATA HM10/.4, .46, .5, .54, .59, .65, .73, .8/
      DATA CD10/.02,.03, .04, .06, .1, .16, .2608, .365/
      DATA HM11/.4, .45, .5, .56, .61, .72, .8/
      DATA CD11/.021, .035, .06, .105, .15, .277, .381/
      CD30F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 9,8,8,9,8,10,8,8,7)
      RETURN
      END
C
      FUNCTION CD35F(T,ALPHAO,HM)
      DIMENSION AO(9),HM3(9),CD3(9),HM4(7),CD4(7),HM5(8),CD5(8),
     1 HM6(8),CD6(8),HM7(8),CD7(8),HM8(8),CD8(8),HM9(8),CD9(8),
     2 HM10(7),CD10(7),HM11(8),CD11(8)
C   DATA IS FROM HAINES AND MONAGHAN, P. 1191, FIG. 15
      DATA AO/3.,4., 5., 6., 7., 8., 9., 10., 11./
      DATA HM3/.57, .6, .62, .65, .68, .71, .75, .78, .8/
      DATA CD3/.02, .025, .0308, .042, .06, .09, .15, .205, .25/
      DATA HM4/.55, .6, .65, .68, .705, .76, .8/
      DATA CD4/.02, .029, .05, .075, .1, .19, .28/
      DATA HM5/.53, .58, .63, .67, .7, .73, .78, .8/
      DATA CD5/.02, .028, .05, .08, .111, .16, .26, .312/
      DATA HM6/.52, .565, .6, .63, .67, .71, .75, .8/
      DATA CD6/.02, .03, .043, .06, .1, .15, .22, .342/
      DATA HM7/.48, .54, .59, .62, .65, .7, .74, .8/
      DATA CD7/.02, .03, .05, .07, .095, .156, .23, .375/
      DATA HM8/.46, .54, .59, .62, .65, .7, .75, .8/
      DATA CD8/.02, .036, .06, .085, .112, .188, .29, .405/
      DATA HM9/.43, .46, .52, .564, .6, .65, .75, .8/
       DATA CD9/.02, .025, .04, .06, .088, .144, .325, .43/
      DATA HM10/.4, .45, .5, .55, .6, .7,.8/
      DATA CD10/.02, .03, .05, .079, .12, .27, .45/
      DATA HM11/.4, .44, .48, .538, .587, .68, .77, .8/
      DATA CD11/.021, .04, .059, .1, .15, .28, .42, .47/
      CD35F=CDTHKF(T,ALPHAO,HM,AO,9,
     1 HM3,HM4,HM5,HM6,HM7,HM8,HM9,HM10,HM11,
     2 CD3,CD4,CD5,CD6,CD7,CD8,CD9,CD10,CD11,
     3 9,7,8,8,8,8,8,7,8)
      RETURN
      END
C
C
C
C
      FUNCTION CDTHKF(T,ALPHAO,HM,AO,NA,
     1 HM1,HM2,HM3,HM4,HM5,HM6,HM7,HM8,HM9,
     2 CD1,CD2,CD3,CD4,CD5,CD6,CD7,CD8,CD9,
     3 N1,N2,N3,N4,N5,N6,N7,N8,N9)
      DIMENSION AO(1),HM1(1),HM2(1),HM3(1),HM4(1),HM5(1),HM6(1),
     1 HM7(1),HM8(1),HM9(1),CD1(1),CD2(1),CD3(1),CD4(1),CD5(1),
     2 CD6(1),CD7(1),CD8(1),CD9(1)
      DIMENSION X(2),Y(2)
      ALP=ALPHAO
      IF(ALP.LE.AO(1)) ALP=AO(1)
      N=2
      CALL OUT(NA,N,IS,IL,AO,ALP)
      DO 30 I=IS,IL
      X(I-IS+1)=AO(I)
      GO TO (1,2,3,4,5,6,7,8,9),I
    1 ANS=GETF(N1,N,HM1,CD1,T,ALPHAO,HM)
      GO TO 20
    2 ANS=GETF(N2,N,HM2,CD2,T,ALPHAO,HM)
      GO TO 20
    3 ANS=GETF(N3,N,HM3,CD3,T,ALPHAO,HM)
      GO TO 20
    4 ANS=GETF(N4,N,HM4,CD4,T,ALPHAO,HM)
      GO TO 20
    5 ANS=GETF(N5,N,HM5,CD5,T,ALPHAO,HM)
      GO TO 20
```

```
    6 ANS=GETF(N6,N,HM6,CD6,T,ALPHAO,HM)
      GO TO 20
    7 ANS=GETF(N7,N,HM7,CD7,T,ALPHAO,HM)
      GO TO 20
    8 ANS=GETF(N8,N,HM8,CD8,T,ALPHAO,HM)
      GO TO 20
    9 ANS=GETF(N9,N,HM9,CD9,T,ALPHAO,HM)
   20 Y(I-IS+1)= ANS
   30 CONTINUE
      CDTHKF=YLAGN(X,Y,N,ALP)
      RETURN
      END
C
C
      FUNCTION GETF(NMAX,N,XHM,YCD,T,ALPHAO,HM)
      DIMENSION XHM(1),YCD(1),U(3),V(3)
      IF(HM.GT.XHM(1)) GO TO 1
      GETF=YCD(1)
      RETURN
    1 CALL OUT(NMAX,N,JS,JL,XHM,HM)
      DO 2 J=JS,JL
      U(J-JS+1)=XHM(J)
      V(J-JS+1)=YCD(J)
    2 CONTINUE
      GETF=YLAGN(U,V,N,HM)
      RETURN
      END
C
      SUBROUTINE OUT(NMAX,N,IS,IL,Y,X)
      DIMENSION Y(1)
      IS=1
      IL=IS+N-1
      IF(X.LE.Y(IL)) RETURN
      IL=NMAX
      IS=IL-N+1
      IF(X.GE.Y(IS)) RETURN
      IS=1
    1 IL=IS+N-1
      IF((X-Y(IS))*(X-Y(IL)).LE. 0.) RETURN
      IS=IL
      GO TO 1
      END
C
C
C
      FUNCTION YLAGN(X,Y,N,Z)
C
C PERFORMS THE LAGRANGE INTERPOLATION
C
      DIMENSION X(1),Y(1)
      SUM=0.
      DO 1 I=1,N
      S=1.
      DO 2 J=1,N
      IF(J.EQ.I) GO TO 2
      S=S*(Z-X(J))/(X(I)-X(J))
    2 CONTINUE
      SUM=SUM+S*Y(I)
    1 CONTINUE
      YLAGN=SUM
      RETURN
C
C-------------------------------------------------------------*
C                                                             *
C                    END OF INFORMATION                       *
C                                                             *
C************************************************************8888
      END
C
C
C
C
      SUBROUTINE ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
C
```

```
      ALTUDE=ALTUDE*.3048
      SLOPE=-.0065
      TEMP=288.16+SLOPE*ALTUDE
      EXP=2.718281828
      TSEA=288.16
      PSEA=101325.
      PRES1=22700.
      GRAV=9.82
      R=288.
      POWER=GRAV/(SLOPE*R)
      PRES=PSEA*(1/(TEMP/TSEA))**POWER
      IF(ALTUDE.LE.11000.) GO TO 1
      PRES=PRES1*EXP**(-GRAV/(R*216.66)*(ALTUDE-11000.))
      TEMP=216.66
    1 WA=SQRT(1.4*R*TEMP)/.3048
      TEMP=(TEMP-273.15)*9/5+491.67
      VIS=.35*(TEMP/492.)**1.5*(690/(TEMP+198.))*.000001
      PRES=PRES*2116.2/PSEA
      DEN=PRES/(1718.*TEMP)
      ALTUDE=ALTUDE/.3048
      RETURN
      END
C
C
      SUBROUTINE CLTMAX(T,NCLD,ALPHLO,DNCLD)
C*************************************************************
C                                                            *
C          DESIGN LIFT COEFFICIENT WITH RESPECT TO MAXIMUM   *
C          THICKNESS AND VISE VERSA FOR CLARK-Y SECTIONS     *
C                                                            *
C                                                            *
C                  REFERENCE: NACA TR 628                    *
C------------------------------------------------------------*
C                                                            *
C   USAGE:                                                   *
C     CALL CLTMAX(T,ALPHA,HM,HML,HMD,ALPHLO,NCLD,T)          *
C                                                            *
C   DESCRIPTION OF PARAMETERS:                               *
C                                                            *
C     ALPHLO  = ANGLE OF ATTACK AT ZERO LIFT (DEGREES)       *
C     TMAX    = MAXIMUM THICKNESS - CHORD RATIO              *
C     AOI     = SECTION LIFT - CURVE SLOPE (DEGREES)         *
C                                                            *
C............................................................*
C............................................................*
C
C DATA IS FROM NACA TR 628
C DATA ALPHLO/-2.9,-3.6,-4.5,-6.2,-7.6,-9.3/
C DATA TMAX/0.06,0.08,0.10,0.14,0.18,0.22/
C DATA CLD/0.2993,0.3642,0.4461,0.5902,0.6944,0.8950/
C DALO(L)=ALPHLO(L),L=1,6
C AOI=DCL/DALO=0.1096*(1-(T/C)MAX(L))/(1-(T/C)MAX(L))**2)**.5
C THUS, CLD=(DCL/DALO)*ABS(DALO)=AOI*ABS(DALO)
C PLOTTING CLD VERSUS (T/C)MAX SHOWS LINEAR RELATIONSHIP
      DIMENSION ALPHAO(21)
      REAL NCLD
      IF(NCLD.NE.0.) GO TO 100
C
C EQUATION OF LINE CLD VERSUS (T/C)MAX: CLD=0.0328125(T/C)MAX+0.234
C
      TCMIN=0.06
      TCMAX=0.22
      IF(T.LT.TCMIN) WRITE(6,20) T,TCMIN
   20 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' OF SUBROUTINE CLTMAX'/)
      IF(T.GT.TCMAX) WRITE(6,30) T,TCMAX
   30 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF SUBROUTINE CLTMAX'/)
      NCLD=(-0.16879+SQRT(0.02849+0.496405*T))/0.2482025
      AOI=AOIOF(T)
C AOIOF(T) CALCULATES SLOPE OF LOW-SPEED LIFT CURVE .
      ALPHLO=NCLD/(-AOI)
      DNCLD=0.
      GO TO 889
```

```
  100 CONTINUE
      CLDMIN=0.30
      CLDMAX=0.90
      IF(NCLD.LT.CLDMIN) WRITE(6,90) NCLD,CLDMIN
   90 FORMAT(' ',29X,'CLD = ',F10.6,' IS LESS THAN CLDMIN = ',F10.6/)
      IF(NCLD.GT.CLDMAX) WRITE(6,105) NCLD,CLDMAX
  105 FORMAT(' ',29X,'CLD = ',F10.6,' IS GREATER THAN CLDMAX = ',F10.6/)
      IF(NCLD.GE.0.0) T=0.1241*NCLD**2+0.16879*NCLD
      IF(NCLD.LE.0.0) T=0.1241*NCLD**2+0.16879*NCLD
      AOI=AOIOF(T)
      ALPHLO=NCLD/(-AOI)
      DNCLD=1.
      GO TO 889
  889 RETURN
      END
C
C
      FUNCTION AOIOF(T)
C AOIOF = VALUE OF A0, SLOPE OF THE LOW SPEED LIFT CURVE
C   T   = MAXIMUM THICKNESS-CHORD RATIO
C
      DIMENSION A(6),H(6),X(3),Y(3)
C DATA IS CALCULATED FROM THE GIVEN INFORMATION FROM NACA TR 628
C
C   DATA A = SLOPE OF LOW-SPEED LIFT CURVE
      DATA A/0.1032,0.1012,0.0991,0.0952,0.0914,0.0876/
C   DATA H = MAXIMUM THICKNESS-CHORD RATIO
      DATA H/0.06,0.08,0.10,0.14,0.18,0.22/
C
      N=2
      AOIOF=0.1096
      IF(T.LT.0.06) RETURN
      IS=1
      IL=IS+N-1
    1 IF(IL.GE.6) GO TO 2
      IF((T-H(IS))*(T-H(IL)).LE.0.) GO TO 3
      IS=IL
      IL=IS+N-1
      GO TO 1
    2 IS=6-N+1
      IL=6
    3 DO 4 I=IS,IL
      X(I-IS+1)=H(I)
      Y(I-IS+1)=A(I)
    4 CONTINUE
      AOIOF=YLAGN(X,Y,N,T)
      RETURN
      END
C
C
      FUNCTION CMFF(T,CL,M,HM)
C*****************************************************************
C                                                               *
C                    MOMENT COEFFICIENTS                        *
C      ABOUT THE QUARTER CHORD AND ABOUT THE LEADING EDGE       *
C                   FOR CLARK - Y SECTIONS                      *
C                                                               *
C...............................................................*
C...............................................................*
C
C
      TCMIN=0.05
      TCMAX=0.25
      IF(T.LT.TCMIN) WRITE(6,10) T,TCMIN
   10 FORMAT(' ',19X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',
     &F10.6,' OF FUNCTION CMFF'/)
      IF(T.GT.TCMAX) WRITE(6,20) T,TCMAX
   20 FORMAT(' ',19X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' OF FUNCTION CMFF'/)
      IF(M.EQ.1) GO TO 1
      IF(M.EQ.2) GO TO 2
      IF(M.EQ.0) GO TO 3
C DATA IS FROM NCSTATE PROGRAM
C DATA ALPHA = ANGLE OF ATTACK RELATIVE TO THE FREESTREAM
```

```
C DATA "CMLE.NO.": "CMLE" = MOMENT COEFFICIENT ABOUT THE
C                           LEADING EDGE
C                  ".NO." = THICKNESS-TO-CHORD RATIO
C DATA "CMQC.NO.": "CMQC" = MOMENT COEFFICIENT ABOUT THE
C                           QUARTER CHORD
C                  ".NO." = THICKNESS-TO-CHORD RATIO
C PLOTTING CM VERSUS CL AT VARYING THICKNESS-TO-CHORD RATIO,
C SHOWS QUADRATIC RELATIONSHIP.
C DATA ALPHA /-4,-2,0,2,4,6,8/
C DATA CMLE5 /.0158,-.0506,-.0814,-.1232,-.1776,-.2247,-.2724/
C DATA CMQC5 /-.0306,-.0387,-.0306,-.0272,-.0306,-.0308,-.0327/
C DATA CMLE10 /-.0692,-.1124,-.1588,-.2131,-.2693,-.3184,-.3635/
C DATA CMQC10 /-.0627,-.0545,-.0579,-.0610,-.0659,-.0679,-.0688/
C DATA CMLE15 /-.1580,-.2064,-.2513,-.3060,-.3600,-.4136,-.4740/
C DATA CMQC15 /-.0959,-.0945,-.0940,-.0988,-.1028,-.1071,-.1158/
C DATA CMLE20 /-.2463,-.2961,-.3359,-.3985,-.4642,-.5266,-.5872/
C DATA CMQC20 /-.1279,-.1282,-.1272,-.1366,-.1468,-.1553,-.1653/
C DATA CMLE25 /-.3239,-.3869,-.4429,-.5037,-.5698,-.6389,-.6996/
C DATA CMQC25 /-.1550,-.1643,-.1700,-.1799,-.1902,-.2055,-.2159/
 1    CONTINUE
      CMLE=T**2*(-.3065*CL+.875)-T*(.1514*CL+.705)-.23993*CL+6.25/100000
      CMLEMX=-.02654*CL**2-.35847*CL-.09792
      IF(CMLE.LT.CMLEMX) WRITE(6,105) CMLE,CMLEMX
  105 FORMAT(' ',19X,'CMLE = ',F10.6,' IS GREATER THAN CMLEMAX = ',
     &F10.6,' OF FUNCTION CMFF'/)
      CMFF=CMLE/SQRT(1-HM**2)
      GO TO 3
 2    CONTINUE
      CMQC=(-.44*CL+1.15)*T**2-(.0993*CL+.785)*T+.0036*CL+.00638
      CMQCMX=-.02545*CL**2-.11281*CL+.09972
      IF(CMQC.LT.CMQCMX) WRITE(6,110) CMQC,CMQCMX
  110 FORMAT(' ',19X,'CMQC = ',F10.6,' IS GREATER THAN CMQCMAX = ',
     &F10.6,' OF FUNCTION CMFF'/)
      CMFF=CMQC/SQRT(1-HM**2)
 3    RETURN
      END
C
C
      SUBROUTINE CYCOOR(L,CHORD,T)
C     ******************************************************************
C     *     THIS ROUTINE WILL GIVE DIMENSIONS AND SECTION PROP         *
C     *  -ERTIES FOR A FLAT FACED CLARK-Y AIRFIOL SECTION FOR ANY      *
C     *  GIVEN THICKNESS AND REFERENCE CHORD.  IT ALSO CALCULATES      *
C     *  THE MOMENT OF INERTIA FOR THE MAJOR AND MINOR AXES.           *
C     *  THE INPUT UNITS WILL CORRESPOND WITH THE OUTPUT UNITS,        *
C     *  HOWEVER THE COORDINATES ARE NON-DIMENSIONAL WITH              *
C     *  THE RESPECT TO THE REFERENCE CHORD. THE UPPER AND LOWER       *
C     *  X-COORDINATES ARE THE SAME.                                   *
C     ******************************************************************
C
C
      DIMENSION X(14),YU(14),YL(14),YU1(13),YL1(13)
      DATA YU1/.294,.55,.665,.808,.959,1.0,.985,.93,.83,.685,.523,.338,.
     &113/
      REAL IMAJOR,IMINOR
      IF(L.EQ.0) GO TO 5
  550 FORMAT('1',///////////////)
  500 FORMAT(' ',45X,'***',1X,'CLARK-Y AIRFOIL COORDINATES',1X,'***',
     &//' ',39X,'X-COORDINATES',5X,'Y-COOR UPPER',6X,'Y-COOR LOWER'/)
  600 FORMAT(' ',39X,F10.6,8X,F10.6,8X,F10.6)
  601 FORMAT('0',//,43X,'***',1X,'CLARK-Y AIRFOIL DIMENSIONS IN FT.',
     &1X,'***',//,' ',39X,'X-COORDINATES',5X,'Y-COORD UPPER',6X,
     &'Y-COORD LOWER',/)
  700 FORMAT(' ',5(/),43X,'(T/C)MAX',7X,'CHORD(FT)',8X,'AREA(FT**2)',
     &/41X,F10.6,6X,F10.6,7X,F10.6)
800   FORMAT(' ',5(/),53X,'MAJOR',12X,'MINOR',/53X,'MOMENT',11X,'MOMENT',
     &/52X,'INERTIA',10X,'INERTIA',/49X,F10.5,7X,F10.5,/53X,'IN**4',
     &12X,'IN**4')
      THICK=T
      IMAJOR=.0418*CHORD**4*THICK
      IMINOR=.0454*CHORD**4*THICK**3
      YL1(1)=YU1(1)
      YL1(2)=.131
      YL1(3)=.0824
```

```
      YL1(4)=.038
      YL1(5)=.0067
      DO 1 I=6,13
    1 YL1(I)=0.0
      X(1)=0.0
      X(2)=.0025
      X(3)=.025
      X(4)=2*X(3)
      DO 2 I=1,10
    2 X(I+4)=FLOAT(I)/10.
      RADLE=.015*CHORD
      RADTE=.086*THICK
      AREA=.7245*CHORD*THICK
      YU(1)=YU1(1)*THICK
      YL(1)=YL1(1)*THICK
      DX=RADLE-X(2)
      DY=SQRT(RADLE**2-DX**2)
      YU(2)=YU(1)+DY
      YL(2)=YL(1)-DY
      DO 3 I=3,14
      YU(I)=YU1(I-1)*THICK
    3 YL(I)=YL1(I-1)*THICK
      NUMPTS=14
      WRITE(6,550)
      WRITE(6,500)
      WRITE(6,600) (X(I),YU(I),YL(I),I=1,NUMPTS)
      WRITE(6,601)
      DO 4 I=1,NUMPTS
      X(I)=X(I)*CHORD
      YU(I)=YU(I)*CHORD
      YL(I)=YL(I)*CHORD
    4 WRITE(6,600)X(I),YU(I),YL(I)
      WRITE(6,700)THICK,CHORD,AREA
      WRITE(6,800)IMAJOR,IMINOR
    5 RETURN
      END
C
C
//$DATA

C
C
```

Appendix II

ClarkY Program Cases

Case 1

Input/Output

```
//CLARKY JOB (R230,006B,S02,003,A7),'CLARKY'
//*MAIN        USER=R230$A7,ORG=XEROX
//*PASSWORD***********************************************************
//*FORMAT PR,DDNAME=,JDE=JFMT1,FORMS=1111
//*XBM WATFIV
C
C************************************************************
C*                                                          *
C*   THIS PROGRAM WILL CALCULATE THE LIFT COEFFICIENT, DRAG, *
C*   AND MOMENT COEFFICIENT ABOUT THE QUARTER CHORD OR THE   *
C*   LEADING EDGE, COORDINATES FOR A CLAYK Y AIRFOIL SECTION *
C*                                                          *
C************************************************************
C
1         DIMENSION CL(25,25),CD(25,25),CLD(25,25),ALPHA(7),ALPHAO(21),
         &RN(25),CM(25,25)
2         REAL HM(4),NCLD
3         DATA HM/0.0,0.1,0.2,0.4/
4         DATA ALPHA/-1.0,0.0,1.0,2.0,3.0,4.0,5.0/
5         DATA ALTUDE/10000./
C
C   NOTE: CHORD MUST BE IN FEET
C
6         DATA CHORD/0.75/
7         DATA NUMACH/4/
8         DATA NUMALP/7/
9         DATA NCL/1/
10        DATA NCD/1/
C
11        CALL ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
C
C SPECIFY HERE THE KNOWN VALUE OF CLD OR TMAX
C SET THE UNKNOWN VARIABLE (CLD OR (T/C)MAX) EQUAL TO ZERO
C FOR EXAMPLE, NCLD=UNKNOWN VALUE OF CLD,T=KNOWN VALUE OF (T/C)MAX
C NOTE: THIS CLD IS INCOMPRESSIBLE AND ONLY TO START THE CODE.
12        DATA NCLD/0.00/
C
C  IN ORDER TO BE CONSISTANT T IS NON-DIMENSIONAL
C
13        DATA T/0.1170/
C
14        CALL CLTMAX(T,NCLD,ALPHLO,DNCLD)
C
C SPECIFY HERE THE DESIRE FOR CLARK - Y AIRFOIL SECTION COORDINATES
C AND ITS MOMENTS OF INERTIA BY INDICATING "1" FOR "YES", AND "O"
C FOR "NO" FOR PARAMETER "L"
C FOR EXAMPLE, L=1
15        DATA L/1/
16        CALL CYCOOR(L,CHORD,T)
C
17        WRITE(6,10)
18     10 FORMAT('1',/////////,56X,'***',1X,'LIMITATIONS',1X,'***'//)
C
C SPECIFY HERE THE DESIRE FOR MOMENT COEFFICIENTS - EITHER CM
C ABOUT THE NOSE OR THE QUARTER CHORD - BY INDICATING "1" FOR
C "CM ABOUT THE NOSE" AND "2" FOR "CM ABOUT THE QUARTER CHORD"
C FOR THE PARAMETER "M".  IF CM IS NOT DESIRED, INDICATE "O" FOR
C PARAMETER "M".
C FOR EXAMPLE, M=1.
19        DATA M/2/
```

*** CLARK-Y AIRFOIL COORDINATES ***

X-COORDINATES	Y-COOR UPPER	Y-COOR LOWER
0.000000	0.034398	0.034398
0.002500	0.041469	0.027327
0.025000	0.064350	0.015327
0.050000	0.077805	0.009641
0.100000	0.094536	0.004446
0.200000	0.112203	0.000784
0.300000	0.117000	0.000000
0.400000	0.115245	0.000000
0.500000	0.108810	0.000000
0.600000	0.097110	0.000000
0.700000	0.080145	0.000000
0.800000	0.061191	0.000000
0.900000	0.039546	0.000000
1.000000	0.013221	0.000000

*** CLARK-Y AIRFOIL DIMENSIONS IN FT. ***

X-COORDINATES	Y-COORD UPPER	Y-COORD LOWER
0.000000	0.025798	0.025798
0.001875	0.031102	0.020495
0.018750	0.048262	0.011495
0.037500	0.058354	0.007231
0.075000	0.070902	0.003334
0.150000	0.084152	0.000588
0.225000	0.087750	0.000000
0.300000	0.086434	0.000000
0.375000	0.081607	0.000000
0.450000	0.072832	0.000000
0.525000	0.060109	0.000000
0.600000	0.045893	0.000000
0.675000	0.029659	0.000000
0.750000	0.009916	0.000000

(T/C)MAX	CHORD(FT)	AREA(FT**2)
0.117000	0.750000	0.063575

MAJOR MOMENT INERTIA	MINOR MOMENT INERTIA
0.00155 IN**4	0.00002 IN**4

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.117000 (S)

CLD = 0.505381

ALPHALO = -5.186451 DEG.

MACH NO. = 0.000000

REYNOLDS NO. = 0.000000E 00

ALPHA	CL	CD	CL/CD	CM(1/4)
-1.000000	0.418226	0.009360	44.680600	-0.075595
0.000000	0.518126	0.009712	53.347590	-0.076998
1.000000	0.618026	0.010203	60.574240	-0.078400
2.000000	0.717926	0.011083	64.776260	-0.079803
3.000000	0.817826	0.011724	69.757200	-0.081206
4.000000	0.917726	0.012258	74.867980	-0.082609
5.000000	1.017626	0.013931	73.047980	-0.084011

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.117000 (S)

CLD = 0.505381

ALPHALO = -5.186451 DEG.

MACH NO. = 0.100000

REYNOLDS NO. = 0.411794E 06

ALPHA	CL	CD	CL/CD	CM(1/4)
-1.000000	0.420333	0.009360	44.905680	-0.076005
0.000000	0.520736	0.009712	53.616340	-0.077422
1.000000	0.621140	0.010203	60.879400	-0.078839
2.000000	0.721543	0.011083	65.102600	-0.080256
3.000000	0.821946	0.011724	70.108620	-0.081673
4.000000	0.922349	0.012258	75.245140	-0.083090
5.000000	1.022752	0.013931	73.415930	-0.084507

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.117000 (S)

CLD = 0.505381

ALPHALO = -5.186451 DEG.

MACH NO. = 0.200000

REYNOLDS NO. = 0.823587E 06

ALPHA	CL	CD	CL/CD	CM(1/4)
-1.000000	0.426850	0.009360	45.601940	-0.077277
0.000000	0.528810	0.009712	54.447640	-0.078738
1.000000	0.630770	0.010203	61.823330	-0.080200
2.000000	0.732730	0.011083	66.111990	-0.081661
3.000000	0.834690	0.011724	71.195640	-0.083122
4.000000	0.936650	0.012258	76.411800	-0.084583
5.000000	1.038610	0.013931	74.554260	-0.086044

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.117000 (S)

CLD = 0.505381

ALPHALO = -5.186451 DEG.

MACH NO. = 0.400000

REYNOLDS NO. = 0.164717E 07

ALPHA	CL	CD	CL/CD	CM(1/4)
-1.000000	0.456322	0.009360	48.750530	-0.083064
0.000000	0.565322	0.009712	58.206980	-0.084734
1.000000	0.674322	0.010203	66.091910	-0.086404
2.000000	0.783321	0.011083	70.676690	-0.088074
3.000000	0.892321	0.011724	76.111350	-0.089744
4.000000	1.001321	0.012258	81.687630	-0.091414
5.000000	1.110320	0.013931	79.701840	-0.093084

Case 2

Input/Output

```
//CLARKY JOB (R230,006B,S02,003,A7),'CLARKY'
//*MAIN        USER=R230$A7,ORG=XEROX
//*PASSWORD*************************************************************
//*FORMAT PR,DDNAME=,JDE=JFMT1,FORMS=1111
//*XBM WATFIV
C
C***************************************************************
C*                                                             *
C*   THIS PROGRAM WILL CALCULATE THE LIFT COEFFICIENT, DRAG,   *
C*   AND MOMENT COEFFICIENT ABOUT THE QUARTER CHORD OR THE     *
C*   LEADING EDGE, COORDINATES FOR A CLAYK Y AIRFOIL SECTION   *
C*                                                             *
C***************************************************************
C
      DIMENSION CL(25,25),CD(25,25),CLD(25,25),ALPHA(7),ALPHAO(21),
     &RN(25),CM(25,25)
      REAL HM(2),NCLD
      DATA HM/0.6,0.85/
      DATA ALPHA/-2.0,0.0,2.0,4.0,6.0,8.0,10.0/
      DATA ALTUDE/10000./
C
C   NOTE: CHORD MUST BE IN FEET
C
      DATA CHORD/0.75/
      DATA NUMACH/2/
      DATA NUMALP/7/
      DATA NCL/1/
      DATA NCD/1/
C
      CALL ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
C
C SPECIFY HERE THE KNOWN VALUE OF CLD OR TMAX
C SET THE UNKNOWN VARIABLE (CLD OR (T/C)MAX) EQUAL TO ZERO
C FOR EXAMPLE, NCLD=UNKNOWN VALUE OF CLD,T=KNOWN VALUE OF (T/C)MAX
C NOTE: THIS CLD IS INCOMPRESSIBLE AND ONLY TO START THE CODE.
      DATA NCLD/0.00/
C
C  IN ORDER TO BE CONSISTANT T IS NON-DIMENSIONAL
C
      DATA T/0.30/
C
      CALL CLTMAX(T,NCLD,ALPHLO,DNCLD)
C
C SPECIFY HERE THE DESIRE FOR CLARK - Y AIRFOIL SECTION COORDINATES
C AND ITS MOMENTS OF INERTIA BY INDICATING "1" FOR "YES", AND "0"
C FOR "NO" FOR PARAMETER "L"
C FOR EXAMPLE, L=1
      DATA L/1/
      CALL CYCOOR(L,CHORD,T)
C
      WRITE(6,10)
   10 FORMAT('1',/////////,56X,'***',1X,'LIMITATIONS',1X,'***'//)
C
C SPECIFY HERE THE DESIRE FOR MOMENT COEFFICIENTS - EITHER CM
C ABOUT THE NOSE OR THE QUARTER CHORD - BY INDICATING "1" FOR
C "CM ABOUT THE NOSE" AND "2" FOR "CM ABOUT THE QUARTER CHORD"
C FOR THE PARAMETER "M".  IF CM IS NOT DESIRED, INDICATE "0" FOR
C PARAMETER "M".
C FOR EXAMPLE, M=1.
      DATA M/2/
```

*** CLARK-Y AIRFOIL COORDINATES ***

X-COORDINATES	Y-COOR UPPER	Y-COOR LOWER
0.000000	0.088200	0.088200
0.002500	0.095271	0.081129
0.025000	0.165000	0.039300
0.050000	0.199500	0.024720
0.100000	0.242400	0.011400
0.200000	0.287700	0.002010
0.300000	0.300000	0.000000
0.400000	0.295500	0.000000
0.500000	0.279000	0.000000
0.600000	0.249000	0.000000
0.700000	0.205500	0.000000
0.800000	0.156900	0.000000
0.900000	0.101400	0.000000
1.000000	0.033900	0.000000

*** CLARK-Y AIRFOIL DIMENSIONS IN FT. ***

X-COORDINATES	Y-COORD UPPER	Y-COORD LOWER
0.000000	0.066150	0.066150
0.001875	0.071453	0.060847
0.018750	0.123750	0.029475
0.037500	0.149625	0.018540
0.075000	0.181800	0.008550
0.150000	0.215775	0.001508
0.225000	0.225000	0.000000
0.300000	0.221625	0.000000
0.375000	0.209250	0.000000
0.450000	0.186750	0.000000
0.525000	0.154125	0.000000
0.600000	0.117675	0.000000
0.675000	0.076050	0.000000
0.750000	0.025425	0.000000

(T/C)MAX	CHORD(FT)	AREA(FT**2)
0.300000	0.750000	0.163012

MAJOR MOMENT INERTIA	MINOR MOMENT INERTIA
0.00397 IN**4	0.00039 IN**4

*** LIMITATIONS ***

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.177439 IS GREATER THAN CMQCMAX = -0.004924 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 12.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 12.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.187114 IS GREATER THAN CMQCMAX = -0.027959 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 14.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 14.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.196789 IS GREATER THAN CMQCMAX = -0.052096 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 16.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 16.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.206464 IS GREATER THAN CMQCMAX = -0.077333 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 18.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 18.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.216139 IS GREATER THAN CMQCMAX = -0.103671 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 20.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 20.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.225814 IS GREATER THAN CMQCMAX = -0.131110 OF FUNCTION CMFF

ALPHAO = ALPHA-ALPHLO = 22.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 22.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.235489 IS GREATER THAN CMQCMAX = -0.159650 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.177439 IS GREATER THAN CMQCMAX = -0.004924 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

ALPHAO = ALPHA-ALPHLO = 12.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 12.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.187114 IS GREATER THAN CMQCMAX = -0.027959 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

ALPHAO = ALPHA-ALPHLO = 14.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 14.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.196789 IS GREATER THAN CMQCMAX = -0.052096 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

ALPHAO = ALPHA-ALPHLO = 16.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 16.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.206464 IS GREATER THAN CMQCMAX = -0.077333 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

ALPHAO = ALPHA-ALPHLO = 18.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 18.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.216139 IS GREATER THAN CMQCMAX = -0.103671 OF FUNCTION CMFF

MACH NO. = 0.850000 IS GREATER THAN MACH NO.(MAX) = 0.800000 OF FUNCTION THKSLP

ALPHAO = ALPHA-ALPHLO = 20.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

ALPHAO = ALPHA-ALPHLO = 20.712020 IS GREATER THAN ALPHAOMAX = 11.000000 OF FUNCTION CDFF

T/C = 0.300000 IS GREATER THAN (T/C)MAX = 0.250000 OF FUNCTION CMFF

CMQC = -0.225814 IS GREATER THAN CMQCMAX = -0.131110 OF FUNCTION CMFF

```
MACH NO. =   0.850000 IS GREATER THAN MACH NO.(MAX) =   0.800000 OF FUNCTION THKSLP
ALPHAO = ALPHA-ALPHLO =  22.712020 IS GREATER THAN ALPHAOMAX =  11.000000 OF FUNCTION CDFF
ALPHAO = ALPHA-ALPHLO =  22.712020 IS GREATER THAN ALPHAOMAX =  11.000000 OF FUNCTION CDFF
T/C =   0.300000 IS GREATER THAN (T/C)MAX =   0.250000 OF FUNCTION CMFF
CMQC =  -0.235489 IS GREATER THAN CMQCMAX =  -0.159650 OF FUNCTION CMFF
```

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.300000 (S)

CLD = 1.016961

ALPHALO = -12.712020 DEG.

MACH NO. = 0.600000

REYNOLDS NO. = 0.247076E 07

ALPHA	CL	CD	CL/CD	CM(1/4)
-2.000000	0.787648	0.132073	5.963749	-0.221799
0.000000	0.934707	0.194073	4.816274	-0.233893
2.000000	1.081765	0.256073	4.224447	-0.245987
4.000000	1.228824	0.318072	3.863345	-0.258080
6.000000	1.375882	0.380072	3.620055	-0.270174
8.000000	1.522942	0.442072	3.445008	-0.282268
10.000000	1.670000	0.504071	3.313024	-0.294362

* CLARK Y SERIES AIRFOIL DATA BANK *

ALTITUDE = 9999.9960 FEET

CHORD = 0.750000 FEET

(T/C)MAX = 0.300000 (S)

CLD = 1.016961

ALPHALO = -12.712020 DEG.

MACH NO. = 0.850000

REYNOLDS NO. = 0.350024E 07

ALPHA	CL	CD	CL/CD	CM(1/4)
-2.000000	0.787648	0.444107	1.773553	-0.336836
0.000000	0.934707	0.457249	2.044195	-0.355202
2.000000	1.081765	0.470393	2.299704	-0.373568
4.000000	1.228824	0.483535	2.541334	-0.391934
6.000000	1.375882	0.496678	2.770166	-0.410301
8.000000	1.522942	0.509821	2.987208	-0.428667
10.000000	1.670000	0.522964	3.193339	-0.447033

II. NACA 4-DIGIT AIRFOIL DATA BANK

1. Introduction

With the advent of the NACA 4-digit family of airfoils, a convenient and systematic method of design was created, treating separately the camber and thickness distributions. For example, the airfoil thickness distribution for the NACA 4-digit family was obtained by uncambering airfoils such as the Gottingen 398 and the Clark-Y. The designation of the NACA 4-digit airfoil family is related to the section geometry where the first integer indicates the maximum value of the mean line ordinate y_c in percent of the chord. The second number indicates the distance from the leading edge to the location of the maximum camber, and the last two digits indicate the thickness of the section in % chord. The NACA 4-digit data bank computer program listed in Appendix I provides lift, drag, and moment coefficients about the airfoil quarter chord or leading edge. The coordinates for these NACA 4-digit airfoils have the maximum camber located at mid-chord, and therefore have the designation X5XX. The data base for the computer code has been derived from the study of McCormick, et.al.(1), and the airfoil coordinates and moment coefficients are calculated using the method of Jacobs, et.al.(2). It should be noted that all interpolation and extrapolation is done by the Lagrangian method in subroutine LINEAR.

The current data bank has been compared to the airfoil analysis code of Smetana, et.al.(3), with the results given in Table I. As noted, the absolute difference between the theoretical predictions of Smetana et.al. and the NACA 4-digit airfoil data bank is acceptable with an average deviation of 6.4% for all cases.

2. Input

The User may specify any airfoil of the NACA 4-digit family which has the maximum camber at the mid-chord position. A maximum of 10 values of $(t/c)_{max}$ may be specified, and either the maximum mean line ordinate in per cent of chord (Z), or the design lift coefficient (C_{l_d}) can be evaluated at any one time. A complete listing of input parameters and associated descriptions is given in Table II. It may be noted that the Reynolds number may be supplied by the variable, RE, or may be computed from CHORD, MACH, and ALT specified in the input. In this case, the variable RE must be set to 0.0, and any value between $4X10^5$ to $1X10^7$ based on airfoil chord is computed.

3. Main Program

The main program routes the various input parameters to the subroutines, with the computations from the subroutines returned to the main program and output. There are, however, several parameters that are computed in the main program. For example, to obtain C_l and C_d it is necessary to initially obtain the optimum lift coefficient, $C_{l_{opt}}$, given by the equation:

$$C_{l_{opt}} = Z\ C(Re)\ D((t/c)max) \qquad \text{II-1}$$

where Z is the (y/c) percentage of maximum camber. The Reynolds number function (C(Re)) and thickness function ($D(t/c)_{max}$) for optimum lift coefficient are expressed as:

$$C(Re) = -14.0(A\log_{10}(Re)-6.0) + 24.5 \qquad \text{II-2}$$

$$D((t/c)max) = -3.8438((t/c)max) + 1.0 \qquad \text{II-3}$$

The drag coefficient is then computed by summing the increments due to lift not being optimum, camber, thickness, and Reynolds number.

When the lift coefficient is not optimum, the increase in drag is found through the parameter, X, given as:

$$X = \frac{C_l - C_{lopt}}{C_{lmax} - C_{lopt}} \qquad \text{II-4}$$

This factor is translated to a ΔC_d by Figure 1 in subroutine CDL. The effects of camber and thickness are found in subroutine CDMN, and the effects of Reynolds number (E(Re)) are obtained in RECD finally yielding:

$$C_{dmin} = C_{dminl}\ E(Re) \qquad \text{II-5}$$

The drag coefficient is then found as a sum of these effects, i.e.,

$$C_d = C_{dmin} + \Delta C_d \qquad \text{II-6}$$

The lift coefficient is a result of the angle of attack, camber, and $(t/c)_{max}$. The design lift coefficient is either given as an input parameter or found from the maximum camber parameter, Z, in subroutine CLDVSZ. The lift-curve slope is computed by a series of IF statements for various $(t/c)_{max}$ values:

$$\frac{dC_l}{d\alpha} = A_o \frac{1-(t/c)max}{\sqrt{1-((t/c)max)^2}} \qquad \text{II-7}$$

A_o is prescribed by the value of $(t/c)_{max}$ as follows:

$(t/c)_{max}$	A_o
> 20%	0.1321
20%-17%	0.1216
16%-14%	0.1175
13%-11%	0.1134
10%-08%	0.1043
07%-05%	0.1039
< 05%	0.1021

The increment of lift due to angle of attack is then calculated by:

$$\Delta C_l = \frac{dC_l}{d\alpha} \alpha \qquad \text{II-8}$$

and is corrected for compressibility effects by the Prandtl-Glauert correction factor:

$$(\Delta C_l)_{comp} = (\Delta C_l)_{inc} / \sqrt{1-M^2} \qquad \text{II-9}$$

Finally, the lift coefficient is found by:

$$C_l = C_l + \Delta C_l \qquad \text{II-10}$$

The remainder of the main program consists of CALL statements for various subroutines and output statements for the data.

4. Subroutine ATMCON

ATMCON calculates the temperature, pressure, speed of sound, density, and viscosity for a specified altitude using the empirical equations of Minzer, et.al.[4] as given by Anderson[5]. These equations have been curve fit from the available data of the ARDC 1959 standard atmosphere[4], and divide the atmosphere into two regions, i.e., from sea level to 11,000 meters, and 11,000 to 25,000 meters. These equations are given as:

<u>Sea level to 11,000 meters.</u>

$$\text{Temp} = 288.16 - 0.0065\, h \qquad \text{II-11}$$

$$P = (101325)/(1/(\text{Temp}/288.16))^{-5.2457} \qquad \text{II-12}$$

<u>11,000 meters to 25,000 meters.</u>

$$\text{Temp} = 216.66 \qquad \text{II-13}$$

$$P = (22{,}703.59)\exp(0.0001547(h-11{,}000)) \qquad \text{II-14}$$

where h is in meters, Temperature is in °K,and pressure P is in N/m^2. The values of P and temperature are converted by;

$$\text{Temp} = (\text{Temp} - 273.15)\ 9/5 + 491.67 \qquad \text{II-15}$$

$$P = 2116.2\ P/101325 \qquad \text{II-16}$$

where Temp and P are now in units of °R and lbs/ft^2, respectively. Values of density, viscosity, and speed of sound are then calculated by;

$$\text{Density} = (\text{Pressure})/(1718)(\text{Temp}) \qquad \text{II-17}$$

$$\text{Viscosity}=3.5\times 10^{-7}(\text{Temp}/492)^{1.5}(690/(\text{Temp}+198)) \qquad \text{II-18}$$

$$\text{Speed of Sound} = \sqrt{(403.2)(\text{Temp})/0.3047} \qquad \text{II-19}$$

where density is on $lb\text{-}ft^2/sec^4$, viscosity in $lb\text{-}sec/ft^2$, and speed of sound in ft/sec.

5. Subroutine CLDVSZ

Subroutine CLDVSZ finds the maximum camber ,Z, if the design lift coefficient, C_{ld}, is input, or will obtain C_{ld} if Z is input given $(t/c)_{max}$. The tabular data contained in the subroutine are for C_{ld} values of 0.2, 0.4, 0.6, and 0.8, and for maximum camber values of 0.02, 0.04, 0.06, 0.08. Data are also contained for $(t/c)_{max}$ values of 4, 6, 9, 12, and 18 percent. If any of the required input correspond to values not listed above, subroutine LINEAR will interpolate between or extrapolate beyond the tabular data.

The data for these relationships were obtained using the airfoil analysis program of Smetana, et.al.[3]. Sweeps were made for different values of C_{ld} and Z for various $(t/c)_{max}$ values. Also, different values of Reynolds number were investigated and shown to have a minimal effect on C_{ld}, therefore Reynolds number was not included as a function of the C_{ld}, Z relationship.

6. Subroutine MAXCL

The maximum lift coefficient is estimated as a function of the maximum camber Z and the thickness of the airfoil, $(t/c)_{max}$. The tabulated data in this subroutine were obtained by taking the values given in Figure 2, i.e., C_{lmax} versus $(t/c)_{max}$ for various Z values, as given by McCormick[1]. The Eppler airfoil analysis code[6] was also used to partially verify the results contained in the data bank.

7. Subroutine CDL

Subroutine CDL finds the effect of lift on the drag coefficient. The data was tabulated from Figure 1 for which the effects of Z were included, and when necessary interpolated using subroutine LINEAR.

8. Subroutine CDMN

The minimum drag coefficient for Reynolds numbers between $6X10^5$ and $1X10^7$ are calculated in the CDMN subroutine. LINEAR is used to interpolate between the tabulated data for 6 values of camber and 12 values of $(t/c)_{max}$ contained within the computer code. These data were taken from Figure 3 and expanded using Smetana, et.al.[3].

9. Subroutine RECD.

Subroutine RECD tabulates the data contained in Figure 4 to add the Reynolds number effects to the minimum drag coefficient. The value obtained is multiplied in the main program by the minimum drag coefficient found previously in CDMN to obtain CDMIN. The Reynolds number effects are such that Reynolds numbers lower than $6X10^5$ increase the minimum drag while Reynolds numbers greater than $5X10^6$ lower the minimum drag.

10. Subroutine FDCOOR

This subroutine calculates the y/c dimensions of a NACA 4-digit airfoil section. The following equations are used in the computation, and the symbols are defined as:

$$X_u = X - Y_t \sin\theta \qquad \text{II-20}$$

$$Y_u = Y_c - Y_t \cos\theta \qquad \text{II-21}$$

$$X_l = X + Y_l \sin\theta \qquad \text{II-22}$$

$$Y_l = Y_c + Y_t \cos\theta \qquad \text{II-23}$$

where ;

$\theta \tan^{-1}(dy_c/dx_c)$

X_u - abscissa of a point on the airfoil upper surface

X_l - abscissa of a point on the airfoil lower surface

X_c - abscissa of point on the mean line

Y_c - ordinate of point on the mean line

Y_u - ordinate of point on the upper surface of a wing section

Y_l - ordinate of point on the upper surface of a wing section

Y_t - ordinate of point on the surface of a symmetrical section

X_u and X_l are at a common chordwise location. Y_t, nondimensionalized by the chord represents the ordinate of the symmetrical thickness distribution found by the equation:

$$\frac{Y_t}{c} = \frac{(t/c)max}{0.20}(0.2969\ X - 0.1260\ X - 0.3516\ X^2 + 0.2843\ X^3 - 0.1015\ X^4) \qquad \text{II-24}$$

where t is the non-dimensional maximum thickness expressed as a fraction of the chord. The leading edge radius nondimensionalized by the chord is defined by:

$$\frac{r_t}{c} = 1.1019\ ((t/c)max)^2 \qquad \text{II-25}$$

The shape of the mean line is expressed analytically as two parabolic arcs that are tangent at the maximum camber location[7], and are expressed as:

(Forward of the maximum ordinate)

$$Y_c = \frac{Z}{P^2}(\ 2\ P\ X - X^2) \qquad \text{II-26}$$

(Aft of the maximum ordinate)

$$Y_c = \frac{Z}{(1-P^2)}\ ((1-2\ P) + 2\ P\ X - X^2) \qquad \text{II-27}$$

Z is the maximum ordinate of the mean line as defined earlier, and P is the chordwise position of the maximum ordinate which has been fixed at 0.5. The y-dimensions are computed at 14 locations to calculate the moment coefficient by subroutine QCCM.

11. Subroutine QCCM

With the coordinates generated in FDCOOR, the moment coefficient is found by applying a method developed by Pankhurst[8] utilizing the airfoil coordinates. The quarter chord moment coefficient is found by the summation:

$$C_{mc/4} = \Sigma B\ (\ Y_u + Y_l) \qquad \text{II-28}$$

where the coefficient B is defined in Table III as a function of the non-dimensional chordwise location, X. The moment coefficient about the leading edge of the airfoil is found from the equation:

$$C_{mle} = C_{mc/4} - 0.25\ C_l \qquad \text{II-29}$$

The effects of compressibility are accounted for by the Prandtl-Glauert factor, i.e.,

$$(C_{mc/4})_{comp} = \frac{(C_{mc/4,le})_{inc}}{\sqrt{1 - M^2}} \qquad \text{II-30}$$

12 Subroutine FDCR

Subroutine FDCR employs the same equations as subroutine FDCOOR. However, 53 stations along the airfoil chord are computed if desired and given in tabular form in the output. This subroutine has been added to allow the User to obtain a detailed set of airfoil coordinates for later use in the airfoil analyses codes of Eppler[6] and Smetana, et.al.[3].

13. Subroutine AREA

This subroutine finds the area, coordinates of the centroid and moments of inertia for the NACA 4-digit airfoil cross section under study. The subroutine employs a trapezoidal integration scheme to find the cross sectional area. The moments of inertia are found by utilizing:

$$IMAJOR = \int_{te}^{le} Y_2 \, dA \qquad (in^4) \qquad \text{II-31}$$

$$IMINOR = \int_{te}^{le} X_2 \, dA \qquad (in^4) \qquad \text{II-32}$$

14. Limitations

The following limits are suggested to guide the User for proper utilization of the NACA 4-digit airfoil data bank. These limitations can be exceeded slightly with minimal error, however caution must be exercised as to the extent these limitations are violated. The Reynolds number for which the airfoil data bank is valid ranges from $4X10^5$ to $10X10^6$, and maximum Z values of less than 0.09.The maximum camber relationship is governed by limits of C_{ld} and $(t/c)_{max}$ as given in subroutine CLDVSZ. The flags appear as:

(1) REYNOLDS NUMBER=0.500000E 04 IS LESS THAN RE(MIN) = 0.400E 06

(2) LIMITATIONS FOR MACH NO. = 0.90

(3) MAX. CAMBER = 0.10 IS GREATER THAN Y/C(MAX) = 0.90 FOR CLD = 0.90
AND T/C = 0.12

15. Output

A sample case is given in Appendix II to show how the code is used, and corresponds to an angle-of-attack sweep from -10 to 8 degrees in increments of 2 degrees at a Mach number of 0.19. The full output was selected to show the capabilities and output format of the computer code.

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5. Anderson, Jr.,J.D., _Introduction to Flight_, McGraw-Hill Book Company, 1978.

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Table I. Percent Difference in Comparison of NACA X5XX Data Bank and Smetana, et. al. Airfoil Analysis Code (Ref. 3).

AIRFOIL	MACH NO	REYNOLDS NO$\times 10^{-6}$	$C_{M_{c/4}}$	LIFT COEFFICIENT, C_L					DRAG COEFFICIENT, C_D				
				-2°	0°	2°	6°	10°	-2°	0°	2°	6°	10°
2503	0.01	3.12	3.7	50.2	*	4.4	0.3	*	9.5	*	-4.5	0.3	*
2504	0.01	1.50	4.2	63.3	9.7	5.9	1.7	*	-1.0	-0.8	0.2	3.6	*
2504	0.01	3.12	2.3	70.4	*	5.9	0.6	*	16.1	*	5.8	20.0	*
2506	0.01	1.50	1.4	157.6	9.3	6.1	2.0	*	-0.6	0.2	1.4	10.1	*
2506	0.01	3.12	-1.1	123.5	*	6.0	0.8	*	4.9	*	8.7	34.7	*
2509	0.01	1.50	0.8	190.8	8.8	3.9	1.2	*	-0.9	-0.3	1.8	9.3	*
2512	0.01	1.50	-2.3	-76.3	8.5	3.9	4.0	*	-4.9	-12.4	-0.3	25.6	*
2512	0.01	3.12	-4.4	125.1	7.0	2.4	2.1	*	6.1	3.5	5.4	53.1	*
2512	0.40	2.91	-	18.0	-7.0	3.0	0.5	*	5.0	3.0	8.0	2.0	*
2515	0.70	3.00	-5.5	-164.5	*	-12.5	-1.1	15.6	-10.1	*	-26.8	*	*
2518	0.01	1.50	-6.9	112.2	8.2	2.3	4.1	*	8.1	0.4	4.4	-1.1	*
2518	0.01	3.12	-9.2	96.8	5.9	0.4	0.2	*	22.8	32.7	35.8	56.9	*
2518	0.20	1.46	-	87.0	*	0.0	1.5	2.0	-3.0	*	-2.0	8.0	1.0
2521	0.70	1.00	22.7	-236.2	*	-0.2	21.3	*	-34.8	*	-50.3	19.2	*
3514	0.60	4.00	-3.5	-31.2	*	-13.9	-3.3	4.2	7.8	*	-3.0	3.9	*
3521	0.60	2.00	13.9	-35.1	*	-10.2	-3.9	18.1	-20.8	*	-30.9	-29.0	*
4503	0.01	3.12	6.4	12.5	*	4.0	11.2	*	-53.0	*	-34.6	-85.3	*
4504	0.01	1.50	2.4	14.7	4.6	3.7	3.0	*	-1.3	0.0	8.6	0.1	*
4504	0.01	3.12	1.7	13.2	*	3.0	1.6	*	11.7	*	14.3	21.9	*
4506	0.01	1.50	1.1	21.8	9.0	7.4	5.3	*	-1.9	-3.0	0.2	-0.1	*
4506	0.01	3.12	-1.4	19.8	*	4.3	3.5	*	6.9	*	0.5	22.6	*
4509	0.01	1.50	0.6	46.4	19.7	14.6	8.8	*	-7.6	-6.4	5.2	-1.7	*

C-2

Table I. (cont)

AIRFOIL	MACH NO	REYNOLDS NOx10^{-6}	$C_{M_{c/4}}$	LIFT COEFFICIENT, C_L -2°	0°	2°	6°	10°	DRAG COEFFICIENT, C_D -2°	0°	2°	6°	10°
4509	0.60	4.37	-5.8	-6.6	*	-11.3	-5.2	1.4	5.9	*	10.8	23.4	*
4512	0.01	1.50	-0.7	27.3	12.9	9.6	6.6	*	3.1	-0.6	1.7	38.3	*
4512	0.01	3.12	-2.3	25.1	10.2	7.7	5.3	*	21.8	36.2	22.0	53.6	*
4512	0.40	2.91	*	3.0	*	-4.0	-1.0	1.0	0.0	*	2.0	21.0	-2.0
4518	0.01	1.50	0.4	8.8	4.3	1.9	3.0	*	-5.8	-1.1	6.1	26.0	*
4518	0.01	3.12	-4.1	3.4	-0.9	-1.6	0.2	*	15.8	16.6	24.4	34.7	*
4518	0.20	1.46	*	2.0	*	-1.4	-0.5	0.5	-1.5	*	-8.0	15.0	-2.0
5506	0.40	3.00	-2.2	-5.3	*	-7.7	-2.6	-0.7	8.4	*	19.8	3.3	*
5512	0.40	4.00	-4.9	-9.7	*	-9.1	-5.1	-1.6	25.6	*	31.6	24.2	-9.8
6504	0.01	1.50	2.6	7.4	3.1	2.0	4.0	*	-3.3	0.3	0.8	1.1	*
6504	0.01	3.12	1.4	4.8	*	-0.2	1.9	*	11.9	*	37.3	38.9	*
6506	0.01	1.50	1.4	12.3	6.0	4.9	6.6	*	-0.1	-0.8	-0.1	4.6	*
6506	0.01	3.12	-0.1	10.3	*	2.0	4.4	*	21.7	-	22.9	40.9	*
6509	0.01	1.50	0.8	28.0	16.3	12.2	7.8	*	-3.5	-7.4	1.8	11.3	*
6509	0.30	3.00	-3.5	12.9	*	1.3	1.9	2.9	3.8	*	16.6	125.0	-14.6
6509	0.50	3.64	-2.1	-1.3	*	-6.1	-3.0	-0.5	5.1	*	6.3	-14.0	*
6512	0.01	1.50	-0.1	2.7	0.0	0.9	0.9	*	-1.1	0.1	-0.7	25.5	*
6512	0.01	3.12	-1.5	-0.1	-2.1	-2.2	0.9	*	18.3	23.6	42.4	27.4	*
6515	0.30	2.00	-5.6	-13.4	*	-10.5	-7.4	-3.4	-0.6	*	5.4	10.9	-24.4
6521	0.30	1.00	-3.3	2.8	*	-0.4	-0.4	1.8	-15.1	*	-3.6	-5.8	-18.1
6521	0.30	2.18	-5.3	-1.8	*	-3.3	-2.7	-0.5	5.1	*	20.0	13.7	-4.3
8504	0.01	1.50	2.0	3.9	2.3	2.0	5.2	*	1.0	-1.5	0.9	0.6	*
8506	0.01	1.50	1.8	5.0	2.3	1.5	5.0	*	1.7	-1.3	0.6	-0.4	*
8506	0.01	3.12	0.7	2.6	0.0	-1.2	3.7	*	36.5	37.1	82.7	45.5	*

Table I. (cont)

AIRFOIL	MACH NO	REYNOLDS NOx10^{-6}	$C_{M_{c/4}}$	LIFT COEFFICIENT, C_L					DRAG COEFFICIENT, C_D				
				-2°	0°	2°	6°	10°	-2°	0°	2°	6°	10°
8509	0.01	1.50	0.9	5.0	2.3	-0.5	-0.7	*	-0.1	1.2	1.1	-0.1	*
8512	0.01	1.50	0.7	5.3	2.2	1.6	1.4	*	-1.4	-0.3	3.4	5.3	*
8512	0.01	3.12	-0.7	2.4	0.5	-0.9	1.2	*	17.4	38.7	39.4	6.2	*
8518	0.01	1.50	0.8	6.4	2.4	0.7	1.4	*	0.7	0.4	0.4	4.7	*
|AVG. % DEV.|			3.3	6.4	6.1	4.5	3.4	5.9	9.6	8.5	13.3	18.7	-9.2

NOTE: *Airfoil analysis codes yielded unrealistic values or did not run.

Table II. NACA 4-Digit Airfoil Data Bank Input Parameters.

ALPHA	Angle(s)-of-Attack.
NUMALP	Number of Alphas.
CLD	Design Lift Coefficient.
NZRCLD	Number of values of CLD or Z to be calculated.
TC	Maximum Thickness-to-Chord ratio.
NUMTC	Number of Thickness-to-Chord values to be calculated.
CHORD	Input in dimensions of feet, which is used for calculation of Reynolds Number.
MACH	Mach Number (Free-Stream).
RE	Reynolds Number. For calculation based on Mach number, Altitude, and Chord set RE=0.0.
ALTITUDE	Geometric Altitude in Feet.
MCP	Moment Coefficinet Parameter =0, if moment coefficients are not desired. =1, for moment coefficient about the quarter-chord. =2, for moment coefficient about the leading-edge. =3, for all moment coefficients.
ACP	Airfoil Coordinates Parameter =0, of Airfoil Coordinates are not desired. =1, for the Airfil dection coordinates.
CAMP	Camber Parameter =0, if CLD is input and is calculated. =1, if Z is input and CLD is calculated.

Table III. Constants for Moment Coefficient Calculation.

X	B
0.0	-0.119
0.025	-0.156
0.05	-0.104
0.1	-0.124
0.2	-0.074
0.3	-0.009
0.4	0.045
0.5	0.101
0.6	0.170
0.7	0.273
0.8	0.477
0.9	0.786
0.95	3.026
1.00	-4.289

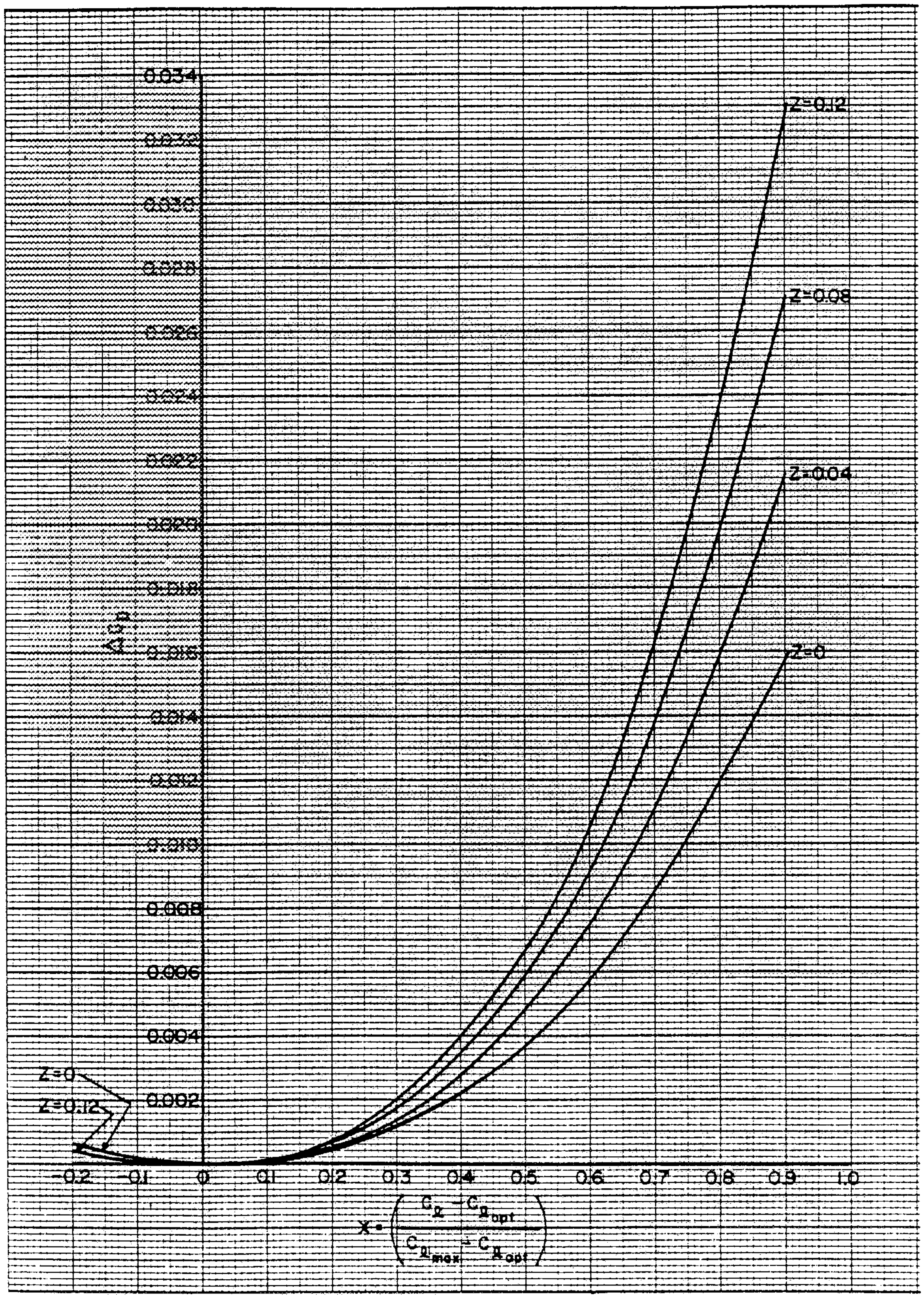

Figure 1. Effect of Lift Coefficient on Drag Coefficient for Four-Digit Airfoils.

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OF POOR QUALITY

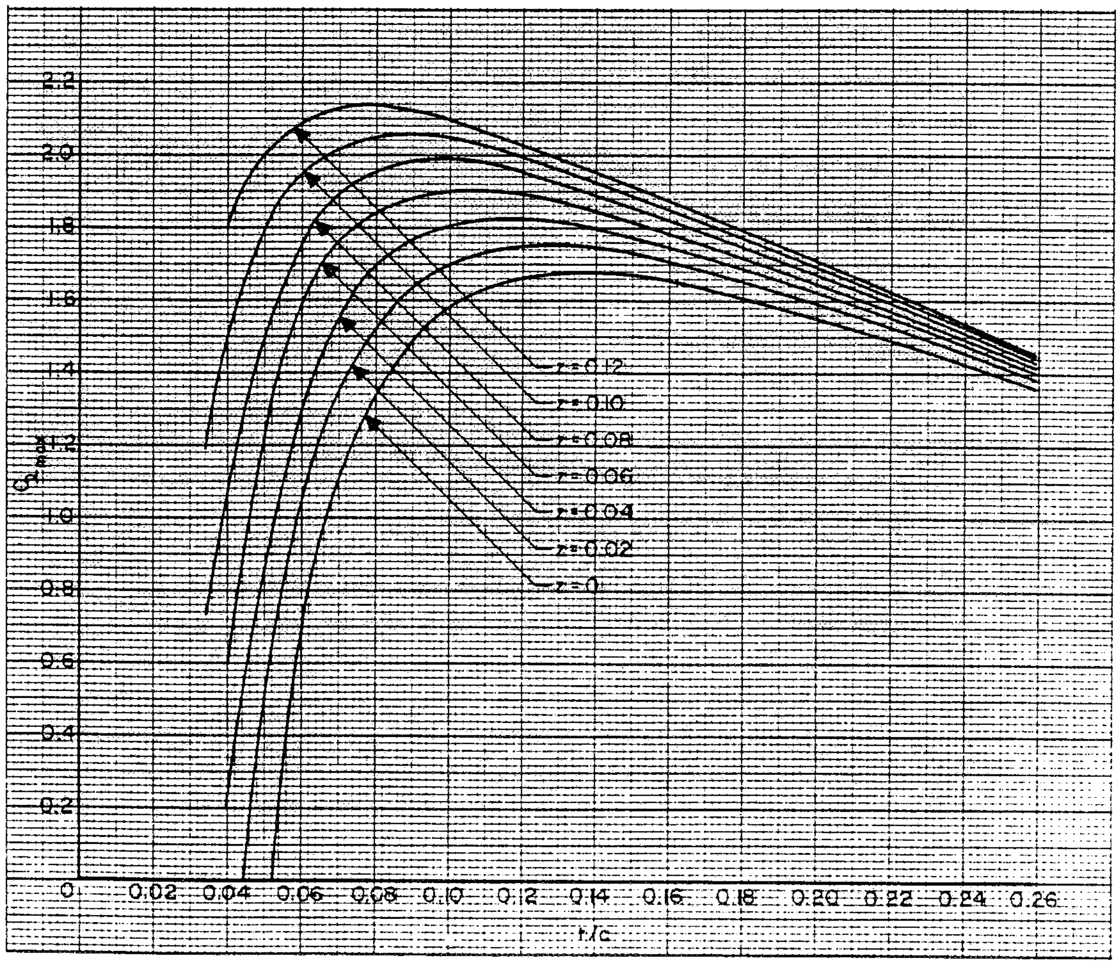

Figure 2. Maximum Lift Coefficients for Four-Digit Airfoils ($R_e = 8 \times 10^6$).

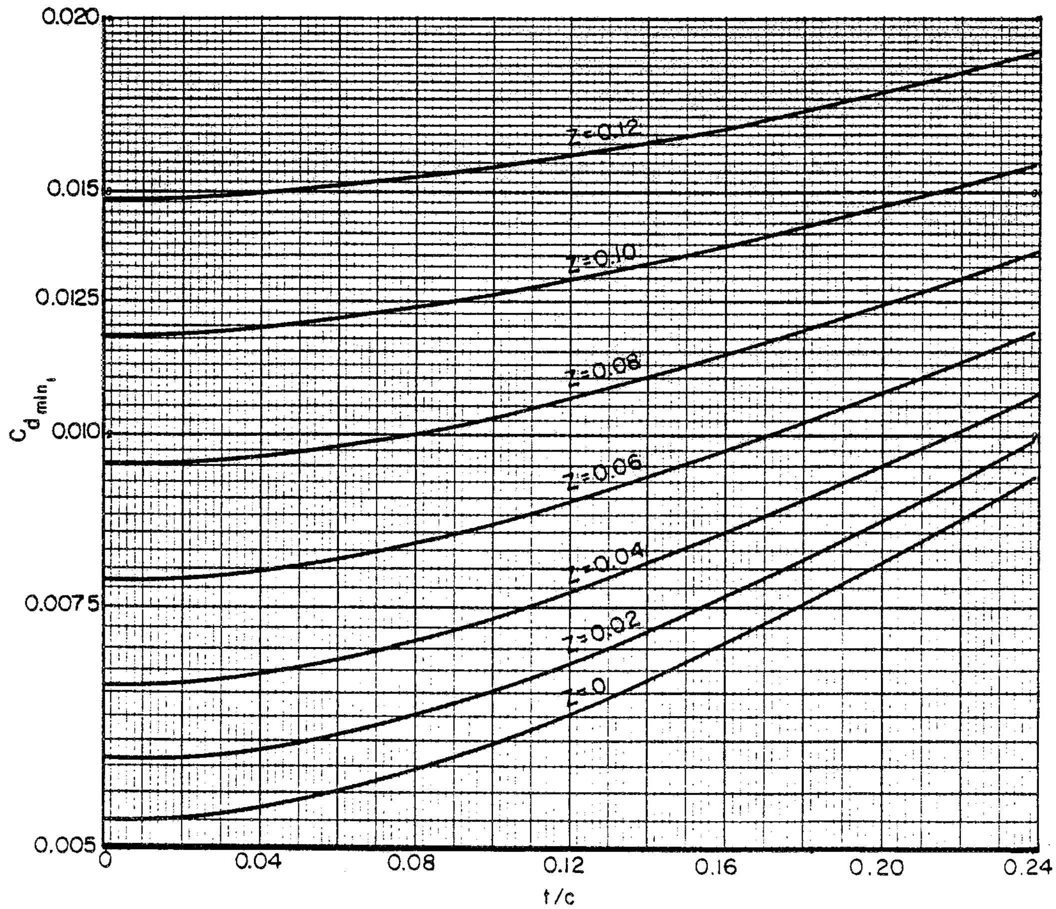

Figure 3. Minimum Drag Coefficients for Four-Digit Airfoils for a Reynolds Number between 6×10^5 and 5×10^6.

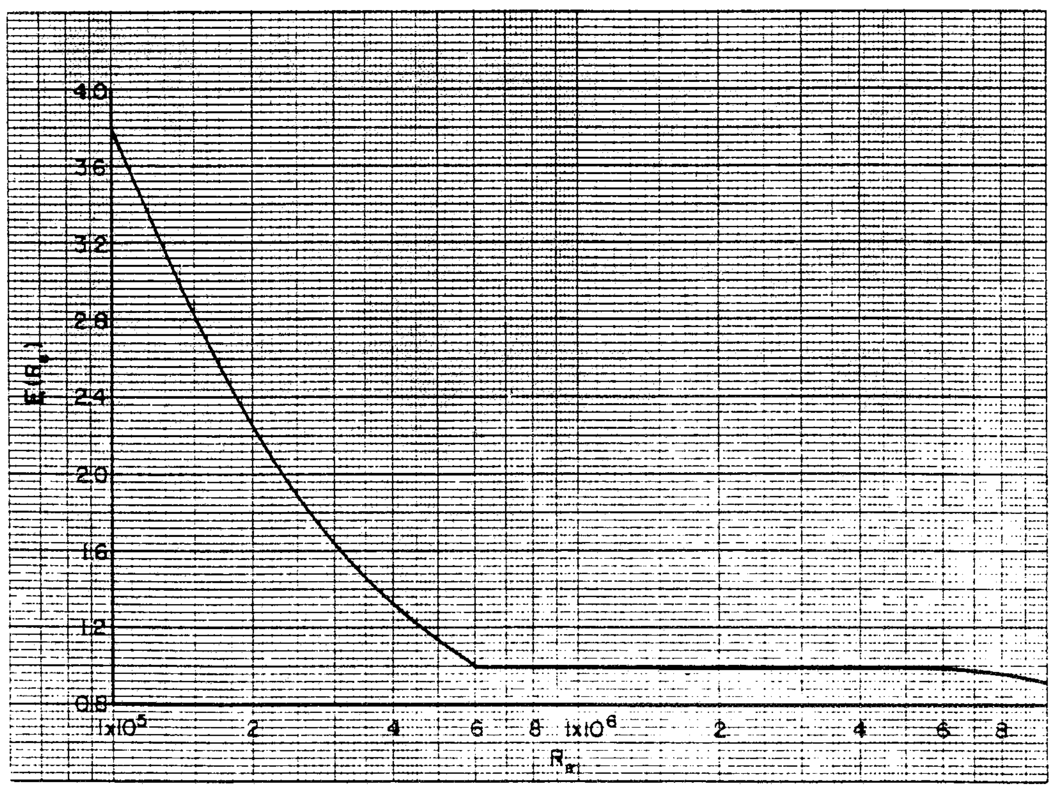

Figure 4. Effect of Reynolds Number on Minimum Drag Coefficient.

Appendix - I

NACA 4-Digit Program Listing

```
//FDBANKA JOB (R205,011C,S02,002,A7),'NACA4DM'
//*XBM WATFIV
//$OPTIONS      NOLIST
C
C
C
C     *************************************************************
C     *                                                           *
C     *     THIS PROGRAM WILL CALCULATE THE LIFT COEFFICIENT,     *
C     *                                                           *
C     *     DRAG COEFFICIENT, MOMENT COEFFICIENT ABOUT THE        *
C     *                                                           *
C     *     QUARTER-CHORD OR THE LEADING EDGE, AND THE COORDIN-   *
C     *                                                           *
C     *     ATES OF A NACA FOUR-DIGIT AIRFOIL SECTION WITH THE    *
C     *                                                           *
C     *     MAXIMUM CAMBER AT THE MID-CHORD POSITION              *
C     *                                                           *
C     *************************************************************
C
C     THE DATA BASE FOR THIS ROUTINE IS FROM:  MCCORMICK,B.W.,EISENHUTH,J.J.,
C     LYNN,J.E.; "A STUDY OF TORPEDO PROPELLERS - PART I", 1956.  THE
C     EQUATIONS AND GRAPHS CONTAINED IN CHAPTER TWO(2) FORM THE BASIS FOR
C     THE CL AND CD CALCULATIONS.  MOMENT COEFFICIENT AND AIRFOIL COORDINATES
C     ARE CALCULATED USING EQUATIONS FROM:  ABBOTT,I.H.,VONDOENHOFF,A.E.;
C     "THEORY OF WING SECTIONS", 1958.  SPECIFIC EQUATIONS OR GRAPHS ARE
C     REFERRED TO WITHIN THE PROGRAM AND AT THE BEGINNING OF EACH SUBROUTINE.
C
C
C       ALPHA = ANGLE OF ATTACK
C
C         CLD = DESIGN LIFT COEFFICIENT
C
C           Z = Y/C PERCENTAGE VALUE OF MAXIMUM CAMBER
C
C          TC = MAXIMUM THICKNESS TO CHORD RATIO
C
C       CHORD = LONGEST CHORD LENGTH (FEET)
C
C        MACH = MACH NUMBER
C
C         ALT = ALTITUDE (FEET)
C
C          RE = REYNOLD'S NUMBER
C
C        CMC4 = MOMENT COEFFICIENT ABOUT THE QUARTER-CHORD
C
C        CMLE = MOMENT COEFFICIENT ABOUT THE LEADING EDGE
C
C       LERAD = LEADING EDGE RADIUS (NON-DIMENSIONALIZED BY THE CHORD)
C
C      NUMALP = NUMBER OF ALPHA'S SPECIFIED
C
C      NZRCLD = NUMBER OF Z'S OR CLD'S SPECIFIED
C
C       NUMTC = NUMBER OF TC'S SPECIFIED
C
C      NUMACH = NUMBER OF MACH NUMBERS SPECIFIED
C
C         MCP = MOMENT COEFFICIENT PARAMETER
C             = 0, IF MOMENT COEFFICIENTS ARE NOT DESIRED
C             = 1, FOR THE MOMENT COEFFICIENT ABOUT THE QUARTER-CHORD
C             = 2, FOR THE MOMENT COEFFICIENT ABOUT THE LEADING EDGE
C             = 3, FOR ALL THE MOMENT COEFFICIENTS
C
C         ACP = AIRFOIL COORDINATES PARAMETER
C             = 0, IF AIRFOIL COORDINATES ARE NOT DESIRED
C             = 1, FOR THE AIRFOIL SECTION COORDINATES
C
C        CAMP = CAMBER PARAMETER
C             = 0, IF CLD IS INPUT AND Z IS CALCULATED
C             = 1, IF Z IS INPUT AND CLD IS CALCULATED
C
C
```

```
C      SPECIFY CLD OR Z, AND NZRCLD; DELETE THE OTHER ONE FROM DATA
C      BUT DIMENSION THEM BOTH EQUALLY
C
C
       REAL ALPHA(10),CLD(1,1),Z(1,1),TC(1),MACH(1),
      &LERAD(10,10),CL(10,10,10),CD(10,10,10),CLMAX(10,10),CMC4(10,10),
      &CMLE(10,10,10),XU(10,10,53),YU(10,10,53),XL(10,10,53),
      &YL(10,10,53),X(10,10,10),TCO(13),BT(13),IMAJ,IMIN
       INTEGER ACP, CAMP
       DATA ALPHA / -10.0,-8.0,-6.0,-4.0,-2.0,0.0,2.0,4.0,6.0,8.0/
       DATA NUMALP / 10 /
       DATA CLD / 0.2 /
       DATA NZRCLD / 1 /
       DATA TC / 0.120 /
       DATA NUMTC / 1 /
       DATA CHORD /1.0/
       DATA MACH / 0.50/
       DATA NUMACH / 1 /
C    SET RE = 0.0 FOR CALCULATION OF RE BASED ON MACH, ALT AND CHORD
       DATA RE / 0.0/
       DATA ALT / 10000.0/
       DATA MCP / 3 /
       DATA ACP / 1 /
       DATA CAMP / 0 /
C    END OF INPUT DATA
       XMEAN = 0.5
       REY = RE
C
       DO 19    M1 = 1, NUMACH
       DO 21    N = 1, NZRCLD
       DO 24    N1 = 1, NUMTC
       DO 31    NN = 1, NUMALP
C
       IF (REY .GT. 0.0) GO TO 88
       CALL ATMCON(ALT,DEN,VIS,WA)
       OMACH = MACH(M1)
       IF (MACH(M1) .EQ. 0.0) MACH(M1) = 0.05
       VEL = MACH(M1)*WA
       RE = DEN*VEL*CHORD/VIS
       MACH(M1) = OMACH
C
   88  CAMB = CAMP
       CALL CLDVSZ( CAMB, TC(N1), CLD(N,N1), Z(N,N1) )
C    CRE   =   REYNOLDS NO. FUNCTION FOR OPTIMUM LIFT COEFFICIENT --
C    FROM FIG. 2-48, MCCORMICK
       CRE   =   -14.0*(ALOG10(RE)-6.0)+24.250
C    DTC   =   THICKNESS FUNCTION FOR OPTIMUM LIFT COEFFICIENT --
C    FROM FIG. 2-49, MCCORMICK
       DTC   =   -3.84375*TC(N1)+1
C    CLOPT FROM EQ. 2-44, MCCORMICK
       CLOPT = Z(N,N1)*CRE*DTC
       CALL MAXCL( Z(N,N1), TC(N1), CLMX )
       IF (ALPHA(NN).EQ. 0.0) GO TO 40
       IF (TC(N1)  .GE.  .20) DCLDAL = .1321*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .20) DCLDAL = .1216*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .17) DCLDAL = .1175*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .14) DCLDAL = .1134*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .11) DCLDAL = .1043*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .08) DCLDAL = .1039*(1-TC(N1))/SQRT(1-TC(N1)**2)
       IF (TC(N1)  .LT.  .05) DCLDAL = .1021*(1-TC(N1))/SQRT(1-TC(N1)**2)
       DCLDAL = DCLDAL/SQRT(1-MACH(M1)**2)
       DELCL = DCLDAL*ALPHA(NN)
       GO TO 50
   40  DELCL = 0.0
   50  CONTINUE
       CL(NN,N,N1) = CLD(N,N1)+DELCL
C
C    X FROM EQ. 2-45, MCCORMICK     X = (CL - CLOPT)/(CLMX - CLOPT)
       X(NN,N,N1) = (CL(NN,N,N1)-CLOPT)/(CLMX-CLOPT)
       CALL CDL( X(NN,N,N1), Z(N,N1), TC(N1), DELCD )
       CALL CDMN( Z(N,N1), TC(N1), CDMN1 )
       CALL RECD ( RE, ERE )
C    CDMIN FROM EQ. 2-46, MCCORMICK
       CDMIN = CDMN1*ERE
```

```
      CD(NN,N,N1) = CDMIN + DELCD
      IF(NN .GT. 1) GO TO 12
      CALL FDCOOR( Z,NZRCLD,TC(N1),YU,YL,N,N1 )
   12 CONTINUE
      IF (MCP .EQ. 0) GO TO 14
      CALL QCCM(CMC4,YU, YL, N, N, NN, MACH(M1), CMLE, CL, N1, Z(N,N1) )
   14 CONTINUE
   31 CONTINUE
      IF(ACP .EQ. 0) GO TO 24
      CALL FDCR( Z,NZRCLD,TC(N1),XU,XL,YU,YL,LERAD,NUMACS,N,N1 )
      CALL AREA( XU,YU,XL,YL,AT,XREF,YREF,IMAJ,IMIN,N,N1,CHORD )
   24 CONTINUE
   21 CONTINUE
C
C
      WRITE(6,260) MACH(M1)
  260 FORMAT('1',T43,'* LIMITATIONS FOR MACH NO. =  ',F6.4,' *'//)
      IF(RE .LT. 4.0E05) WRITE(6,261) RE
  261 FORMAT(T5,'REYNOLDS NO. =  ',E12.6,'  IS LESS THAN RE(MIN)
     &= 0.400E 06')
      IF(RE .GT. 0.10E08) WRITE(6,262) RE
  262 FORMAT(T5,'REYNOLDS NO. =  ',E12.6,'  IS GREATER THAN RE(MAX)
     &= 0.100E 08' )
      DO 263  I = 1,NZRCLD
      DO 264  I1 = 1,NUMTC
      IF(Z(I,I1) .GT. 0.09) WRITE(6,265) Z(I,I1), CLD(I,I1), TC(I1)
  265 FORMAT(T5,'MAX. CAMBER = ',F10.6,'  IS GREATER THAN Y/C(MAX)
     &= 0.090 FOR CLD = ',F10.6,'AND T/C = ',F10.6)
  264 CONTINUE
  263 CONTINUE
      WRITE(6,271)
  271 FORMAT('-',T53,'* END LIMITATIONS *'///)
      WRITE(6,999)
  999 FORMAT('1')
      DO 11  L = 1,NZRCLD
      NTC = NUMTC
      DO 111  L1 = 1,NUMTC,2
      IF (ACP .EQ. 0) GO TO 5
      IF (NUMTC .EQ. 1) GO TO 800
      IF (CAMP .EQ. 1) GO TO 41
      WRITE(6,15)
   15 FORMAT('-',9X,'* NACA 4-DIGIT SERIES AIRFOIL COORDINATES *',
     &18X,'* NACA 4-DIGIT SERIES AIRFOIL COORDINATES *'///)
      GO TO 13
   41 IZ = Z(L,L1)*101
      IZP = Z(L,L1+1)*101
      ITC = TC(L1)*101
      ITCP = TC(L1+1)*101
      IF(ITCP .LT. 10) WRITE(6,43) IZ,ITC,IZP,ITCP
      IF(ITCP .GE. 10) WRITE(6,42) IZ,ITC,IZP,ITCP
   42 FORMAT('1',2(14X,'* NACA ',I1,'5',I2,' AIRFOIL COORDINATES *',9X))
   43 FORMAT('1',2(14X,'* NACA',I2,'50',I1,' AIRFOIL COORDINATES *',9X))
   13 CONTINUE
      WRITE(6,25) CLD(L,L1), CLD(L,L1+1)
   25 FORMAT('-',T30,'CLD =     ',F10.6,T92,'CLD =     ',F10.6/)
      WRITE(6,35) TC(L1), TC(L1+1)
   35 FORMAT(T25,'(T/C)MAX =     ',F10.6,T87,'(T/C)MAX =     ',F10.6/)
      WRITE(6,36) LERAD(L,L1), LERAD(L,L1+1)
   36 FORMAT(T28,'LERAD =     ',F10.6,T90,'LERAD =     ',F10.6/)
      WRITE(6,45) XMEAN, XMEAN
   45 FORMAT(T9,'X/C VALUE OF MAX. CAMBER =     ',F10.6,T71,
     &'X/C VALUE OF MAX. CAMBER =     ',F10.6/)
      WRITE(6,55) Z(L,L1), Z(L,L1+1)
   55 FORMAT(T9,'Y/C VALUE OF MAX. CAMBER =     ',F10.6,T71,
     &'Y/C VALUE OF MAX. CAMBER =     ',F10.6//)
      WRITE(6,65)
   65 FORMAT(T13,'XUPPER',T25,'YUPPER',T37,'XLOWER',T49,'YLOWER',
     &T76,'XUPPER',T88,'YUPPER',T100,'XLOWER',T112,'YLOWER'/)
C
      DO 66 M = 1, NUMACS
      WRITE(6,75) XU(L,L1,M),YU(L,L1,M),XL(L,L1,M),YL(L,L1,M),
     &XU(L,L1+1,M),YU(L,L1+1,M),XL(L,L1+1,M),YL(L,L1+1,M)
   75 FORMAT(2(9X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,8X))
   66 CONTINUE
```

```
      GO TO 99
 800  IF (ACP .EQ. 0) GO TO 900
      K1 = NUMTC
      IF (CAMP .EQ. 1) GO TO 141
      WRITE(6,115)
 115  FORMAT('-',9X,'* NACA 4-DIGIT SERIES AIRFOIL COORDINATES *'///)
      GO TO 113
 141  IZ = Z(L,K1)*101
      ITC = TC(K1)*101
      IF(ITC .GE. 10) WRITE(6,142) IZ,ITC
      IF(ITC .LT. 10) WRITE(6,114) IZ,ITC
 142  FORMAT('1',14X,'* NACA ',I1,'5',I2,' AIRFOIL COORDINATES *')
 114  FORMAT('1',14X,'* NACA ',I1,'50',I1,' AIRFOIL COORDINATES *')
 113  CONTINUE
      WRITE(6,999)
      WRITE(6,125) CLD(L,K1)
 125  FORMAT('-',T30,'CLD =    ',F10.6/)
      WRITE(6,135) TC(K1)
 135  FORMAT(T25,'(T/C)MAX =    ',F10.6/)
      WRITE(6,136) LERAD(L,K1)
 136  FORMAT(T28,'LERAD =    ',F10.6/)
      WRITE(6,145) XMEAN
 145  FORMAT(T9,'X/C VALUE OF MAX. CAMBER =    ',F10.6/)
      WRITE(6,155) Z(L,K1)
 155  FORMAT(T9,'Y/C VALUE OF MAX. CAMBER =    ',F10.6//)
      WRITE(6,165)
 165  FORMAT(T13,'XUPPER',T25,'YUPPER',T37,'XLOWER',T49,'YLOWER'/)
C
      DO 166 M = 1, NUMACS
      WRITE(6,175) XU(L,K1,M),YU(L,K1,M),XL(L,K1,M),YL(L,K1,M)
 175  FORMAT(9X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6)
 166  CONTINUE
C
      GO TO 900
   5  IF (NUMTC .EQ. 1) GO TO 900
  99  WRITE(6,100)
 100  FORMAT('-',11X,'* NACA 4-DIGIT SERIES AIRFOIL DATA BANK *',
     &20X,'* NACA 4-DIGIT SERIES AIRFOIL DATA BANK *')
      IF (CAMP .EQ. 0) GO TO 104
      IZ = Z(L,L1)*101
      IZP = Z(L,L1+1)*101
      ITC = TC(L1)*101
      ITCP = TC(L1+1)*101
      IF(ITCP .LT. 10) WRITE(6,108) IZ,ITC,IZP,ITCP
      IF(ITCP .GE. 10) WRITE(6,105) IZ,ITC,IZP,ITCP
 105  FORMAT(2(25X,'* NACA ',I1,'5',I2,' *',14X))
 108  FORMAT(2(25X,'* NACA ',I1,'50',I1,' *',14X))
 104  CONTINUE
      WRITE(6,200) CLD(L,L1), CLD(L,L1+1)
 200  FORMAT(///,T25,'CLD =    ',F10.6,T87,'CLD =    ',F10.6/)
      WRITE(6,300) TC(L1), TC(L1+1)
 300  FORMAT(T20,'(T/C)MAX =    ',F10.6,T82,'(T/C)MAX =    ',F10.6/)
      WRITE(6,301) MACH(M1), MACH(M1)
 301  FORMAT(T20,'MACH NO. =    ',F10.6,T82,'MACH NO. =    ',F10.6/)
      WRITE(6,400) RE, RE
 400  FORMAT(T16,'REYNOLDS NO. =    ',E14.6,T79,'REYNOLDS NO. =    '
     &,E14.6/)
      IF (MCP .EQ. 0) GO TO 101
      IF (MCP .EQ. 2) GO TO 101
      WRITE(6,500) CMC4(L,L1), CMC4(L,L1+1)
 500  FORMAT(T24,'CMC4 =    ',F10.6,T86,'CMC4 =    ',F10.6//)
 101  CONTINUE
      IF (MCP .EQ. 2) GO TO 501
      IF (MCP .EQ. 3) GO TO 501
      WRITE(6,600)
 600  FORMAT(T20,'ALPHA',T33,'CL',T45,'CD',T83,'ALPHA',T96,
     &'CL',T108,'CD'/)
      GO TO 107
 501  WRITE(6,601)
 601  FORMAT(T13,'ALPHA',T26,'CL',T38,'CD',T49,'CMLE',T76,
     &'ALPHA',T89,'CL',T101,'CD',T112,'CMLE'/)
 107  CONTINUE
C
      DO 10  J = 1, NUMALP
```

```
      IF (MCP .EQ. 2) GO TO 106
      IF (MCP .EQ. 3) GO TO 106
      WRITE(6,802) ALPHA(J),CL(J,L,L1),CD(J,L,L1),ALPHA(J),
     &CL(J,L,L1+1),CD(J,L,L1+1)
 802  FORMAT(2(15X,F10.6,2X,F10.6,2X,F10.6,15X))
      GO TO 10
 106  WRITE(6,801) ALPHA(J),CL(J,L,L1),CD(J,L,L1),CMLE(J,L,L1),
     &ALPHA(J),CL(J,L,L1+1),CD(J,L,L1+1),CMLE(J,L,L1+1)
 801  FORMAT(2(8X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,9X))
  10  CONTINUE
      NTC = NTC - 2
      IF (NTC .EQ. 0) GO TO 11
      IF (NTC .EQ. 1) GO TO 800
 111  CONTINUE
 900  K1 = NUMTC
      WRITE(6,901)
 901  FORMAT('-',11X,'* NACA 4-DIGIT SERIES AIRFOIL DATA BANK *')
      IF (CAMP .EQ. 0) GO TO 902
      IZ = Z(L,K1)*101
      ITC = TC(K1)*101
      IF(ITC .LT. 10) WRITE(6,903) IZ,ITC
      IF(ITC .GE. 10) WRITE(6,920) IZ,ITC
 903  FORMAT(25X,'* NACA ',I1,'50',I1,' *')
 920  FORMAT(25X,'* NACA ',I1,'5',I2,' *')
 902  CONTINUE
      WRITE(6,904) CLD(L,K1)
 904  FORMAT(///,T25,'CLD =     ',F10.6/)
      WRITE(6,906) TC(K1)
 906  FORMAT(T20,'(T/C)MAX =     ',F10.6/)
      WRITE(6,907) MACH(M1)
 907  FORMAT(T20,'MACH NO. =     ',F10.6/)
      WRITE(6,910) RE
 910  FORMAT(T16,'REYNOLDS NO. =     ',E14.6/)
      WRITE(6,708)AT,XREF,YREF
 708  FORMAT(T24,'AREA =     ',F10.6,'   IN**2',/,T19,'XCENTRIOD =     '
     ,,F10.6,'   IN',/,T19,'YCENTRIOD =     ',F10.6,'   IN',/)
      WRITE(6,709)IMAJ,IMIN
 709  FORMAT(T22,'IMAJOR = ',F10.3,'   IN**4',/,T22,'IMINOR =   ',F10.7,'
     *IN**4',/)
      IF (MCP .EQ. 0) GO TO 908
      IF (MCP .EQ. 2) GO TO 908
      WRITE(6,909) CMC4(L,K1)
 909  FORMAT(T24,'CMC4 =     ',F10.6//)
 908  CONTINUE
      IF (MCP .EQ. 2) GO TO 911
      IF (MCP .EQ. 3) GO TO 911
      WRITE(6,912)
 912  FORMAT(T20,'ALPHA',T33,'CL',T45,'CD'/)
      GO TO 913
 911  WRITE(6,914)
 914  FORMAT(T13,'ALPHA',T26,'CL',T38,'CD',T49,'CMLE'/)
 913  CONTINUE
C
      DO 919  J = 1, NUMALP
      IF (MCP .EQ. 2) GO TO 916
      IF (MCP .EQ. 3) GO TO 916
      WRITE(6,917) ALPHA(J),CL(J,L,K1),CD(J,L,K1)
 917  FORMAT(15X,F10.6,2X,F10.6,2X,F10.6)
      GO TO 915
 916  WRITE(6,918) ALPHA(J),CL(J,L,K1),CD(J,L,K1),CMLE(J,L,K1)
 918  FORMAT(8X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6)
 915  CONTINUE
 919  CONTINUE
  11  CONTINUE
  19  CONTINUE
      WRITE(6,999)
      STOP
      END
C
C
C   SUBROUTINE ATMCON FINDS PARAMETERS AT GIVEN ALTITUDE
      SUBROUTINE ATMCON(ALT,DEN,VIS,WA)
      ALT = ALT*.3048
      SLOPE = -.0065
```

```
      TEMP = 288.16+SLOPE*ALT
      EXP = 2.718281828
      TSEA = 288.16
      PSEA = 101325.
      PRES1 = 22700.
      GRAV = 9.82
      R = 288.
      POWER = GRAV/(SLOPE*R)
      PRES = PSEA*(1/(TEMP/TSEA))**POWER
      IF(ALT .LE. 11000.) GO TO 4
      PRES = PRES1*EXP**(-GRAV/(R*216.66)*(ALT-11000.))
      TEMP = 216.66
    4 WA = SQRT(1.4*R*TEMP)/.3048
      TEMP = (TEMP-273.15)*9/5+491.67
      VIS = .35*(TEMP/492.)**1.5*(690/(TEMP+198.))*.000001
      PRES = PRES*2116.2/PSEA
      DEN = PRES/(1718.*TEMP)
      ALT = ALT/.3048
      RETURN
      END
C
C   SUBROUTINE CLDVSZ CALCULATES DESIGN LIFT COEFFICIENT IF
C   CAMBER IS INPUT OR VICE VERSA
      SUBROUTINE CLDVSZ( CAMP, TC, CLD, Z )
      DIMENSION CLDATA(5,4),ZDATA(5,4),ZI(4),CLDI(4),TCI(5),
     &CLD02(5),CLD04(5),CLD06(5),CLD08(5),Z2(5),Z4(5),Z6(5),
     &Z8(5),ZADATA(4),CLDTA(4)
      EQUIVALENCE(CLDATA(1,1), CLD02 )
      EQUIVALENCE(CLDATA(1,2), CLD04 )
      EQUIVALENCE(CLDATA(1,3), CLD06 )
      EQUIVALENCE(CLDATA(1,4), CLD08 )
C
      EQUIVALENCE(ZDATA(1,1), Z2 )
      EQUIVALENCE(ZDATA(1,2), Z4 )
      EQUIVALENCE(ZDATA(1,3), Z6 )
      EQUIVALENCE(ZDATA(1,4), Z8 )
C
      DATA ZI / 0.02,0.04,0.06,0.08 /
      DATA CLDI / 0.2,0.4,0.6,0.8 /
      DATA TCI / 0.04,0.06,0.09,0.12,0.18 /
      DATA CLD02 / .225537,.235576,.246819,.256079,.265394 /
      DATA CLD04 / .455984,.48389,.547405,.52539,.489006 /
      DATA CLD06 / .672912,.707067,.786416,.691206,.6380 /
      DATA CLD08 / .892327,.899246,.906358,.930514,.843705 /
C
      DATA Z2 / .0195,.0186,.0175,.0168,.0160 /
      DATA Z4 / .0370,.0360,.0350,.0340,.0330 /
      DATA Z6 / .0550,.0540,.0530,.0520,.0530 /
      DATA Z8 / .0730,.0720,.0710,.0700,.0760 /
C
      IF (CAMP .EQ. 1) GO TO 10
      DO 20  I = 1,4
      CALL LINEAR(5,TCI,ZDATA(1,I),TC,ZADATA(I))
   20 CONTINUE
      CALL LINEAR(4,CLDI,ZADATA,CLD,Z)
      GO TO 30
   10 CONTINUE
      DO 40  J = 1,4
      CALL LINEAR(5,TCI,CLDATA(1,J),TC,CLDTA(J))
   40 CONTINUE
      CALL LINEAR(4,ZI,CLDTA,Z,CLD)
   30 RETURN
      END
C
C   SUBROUTINE MAXCL ESTIMATES CL(MAX) TO AID IN FINDING
C   THE DRAG COEFFICIENT INCREASE DUE TO THICKNESS
      SUBROUTINE MAXCL(Z, TC, CLMX )
      REAL  LDATA(7,5),LADATA(5),Z1(5),TC1(7)
      DIMENSION CLM00(7), CLM02(7), CLM04(7), CLM06(7), CLM08(7)
      EQUIVALENCE (LDATA(1,1), CLM00)
      EQUIVALENCE (LDATA(1,2), CLM02)
      EQUIVALENCE (LDATA(1,3), CLM04)
      EQUIVALENCE (LDATA(1,4), CLM06)
      EQUIVALENCE (LDATA(1,5), CLM08)
```

```
C
      DATA Z1 / 0.0,0.02,0.04,0.06,0.08 /
      DATA TC1  / 0.03,.06,.09,.12,.15,.18,.21 /
      DATA CLM00 / 1.4,1.3,1.4,1.4,1.4,1.4,1.4 /
      DATA CLM02 / 1.5,1.4,1.5,1.5,1.4,1.4,1.3 /
      DATA CLM04 / 1.65,1.6,1.7,1.7,1.65,1.6,1.55 /
      DATA CLM06 / 1.8,1.9,1.9,1.8,1.7,1.8,1.65 /
      DATA CLM08 / 2.0,2.1,2.1,2.0,1.9,1.8,1.7 /
C
      DO 130 IA = 1, 5
      CALL LINEAR( 7, TC1,  LDATA(1,IA), TC, LADATA(IA) )
 130  CONTINUE
      CALL LINEAR( 5, Z1, LADATA, Z, CLMX )
      RETURN
      END
C
C
C
C
C   SUBROUTINE CDL FINDS THE EFFECT OF LIFT COEFFICIENT ON DRAG
C   COEFFICIENT -- FROM FIG. 2-52, MCCORMICK (PLUS INCORPORATION OF T/C(MAX))
      SUBROUTINE CDL( X, Z, TC, DELCD )
      DIMENSION DCD(17,4,5),DECD(5),DLCD(4),ZP(4),TCP(5),XP(17),
     &X2(9),X4(11),X6(12),X8(17)
      DIMENSION DCD204(9),DCD206(9),DCD209(9),DCD212(9),DCD218(9),
     &DCD404(11),DCD406(11),DCD409(11),DCD412(11),DCD418(11),
     &DCD604(12),DCD606(12),DCD609(12),DCD612(12),DCD618(12),
     &DCD804(17),DCD806(17),DCD809(17),DCD812(17),DCD818(17)
      EQUIVALENCE (DCD(1,1,1), DCD204)
      EQUIVALENCE (DCD(1,1,2), DCD206)
      EQUIVALENCE (DCD(1,1,3), DCD209)
      EQUIVALENCE (DCD(1,1,4), DCD212)
      EQUIVALENCE (DCD(1,1,5), DCD218)
C
      EQUIVALENCE (DCD(1,2,1), DCD404)
      EQUIVALENCE (DCD(1,2,2), DCD406)
      EQUIVALENCE (DCD(1,2,3), DCD409)
      EQUIVALENCE (DCD(1,2,4), DCD412)
      EQUIVALENCE (DCD(1,2,5), DCD418)
C
      EQUIVALENCE (DCD(1,3,1), DCD604)
      EQUIVALENCE (DCD(1,3,2), DCD606)
      EQUIVALENCE (DCD(1,3,3), DCD609)
      EQUIVALENCE (DCD(1,3,4), DCD612)
      EQUIVALENCE (DCD(1,3,5), DCD618)
C
      EQUIVALENCE (DCD(1,4,1), DCD804)
      EQUIVALENCE (DCD(1,4,2), DCD806)
      EQUIVALENCE (DCD(1,4,3), DCD809)
      EQUIVALENCE (DCD(1,4,4), DCD812)
      EQUIVALENCE (DCD(1,4,5), DCD818)
C
C
      DATA ZP / 0.02,0.04,0.06,0.08 /
      DATA TCP / 0.04,.06,.09,.12,.18 /
      DATA X2 / -0.3,-.2,-.1,0.,.1,.2,.3,.4,.5 /
      DATA X4 / -0.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,.4,.5 /
      DATA X6 / -0.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,.4 /
      DATA X8 / -1.1,-1.0,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,
     01,.2,.3,.4,.5 /
C
      DATA DCD204 / .00065,.0003,0.,0.,.0003,.00065,.0011,
     &.0017,.0025 /
      DATA DCD206 / .0009,.00035,.0001,0.,.00025,.0008,.0018,
     &.0032,.0046 /
      DATA DCD209 / .0014,.0006,.0002,.0002,.0006,.0012,.0026,
     &.0042,.0058 /
      DATA DCD212 / .0014,.0008,.0003,.0002,.0001,0.,.0015,
     &.0036,.0058 /
      DATA DCD218 / .0021,.0018,.0013,0.,.001,.0015,.0019,
     &.0023,.0041 /
C
      DATA DCD404 / .0008,.00045,.0002,.0001,0.,.00015,.0004,.0008,
     &.0015,.0022,.0030 /
```

```
       DATA DCD406 / .0016,.0013,.001,.00065,.0002,0.,.0006,.0017,
      &.003,.0044,.0059 /
       DATA DCD409 / .001,.0007,.0005,.0002,0.,0.,0.,.0008,
      &.0021,.0036,.0052 /
       DATA DCD412 / .0012,.0007,.0004,.0002,.0005,0.,.0001,.0003,
      &.0022,.0040,.0066 /
       DATA DCD418 / .0042,.0037,.0032,.0026,.002,.0008,.0001,.0001,
      &.0018,.0032,.0051 /
C
       DATA DCD604 / .0013,.0011,.001,.0011,.0013,.0016,.0021,.0028,
      &.0037,.0047,.0057,.0067 /
       DATA DCD606 / .0015,.0014,.00135,.0013,.0013,.0013,.00135,.0018,
      &.0027,.0042,.0062,.008 /
       DATA DCD609 / .0005,.0004,.00045,.0006,.0007,.0003,.0003,.0009,
      &.001,.0018,.0032,.005 /
       DATA DCD612 / .0020,.0018,.0016,.0013,.001,.0008,.0005,.00045,
      &.001,.0028,.0039,.0053 /
       DATA DCD618 / .0021,.0019,.0015,.0011,.0009,.001,.0015,.0012,
      &.0015,.0020,.0040,.0054 /
C
       DATA DCD804 / .0030,.0029,.0028,.0027,.00275,.003,.0034,.004,
      &.0049,.0057,.0066,.0074,.0082,.009,.0098,.0106,.0113 /
       DATA DCD806 / .0025,.0023,.0024,.0028,.0032,.0034,.003,.0025,
      &.0024,.003,.0045,.006,.0075,.009,.0105,.012,.0135 /
       DATA DCD809 / .0005,.0006,.0007,.0008,.001,.0012,.0016,.0019,
      &.0023,.0027,.0031,.0035,.0038,.0041,.0044,.0047,.0049 /
       DATA DCD812 / .0013,.0012,.001,.0008,.0007,.0006,.0005,.00045,
      &.0004,.00035,.0004,.0007,.0023,.0038,.0041,.0044,.0047 /
       DATA DCD818 / .0005,.0004,.0003,.0002,.0001,0.,0.,0.,.0001,
      &.0002,.00025,.0006,.0012,.003,.0035,.0038,.0047 /
C
       DO 102  I = 1,4
       DO 103  J = 1,5
       IF (I .EQ. 1) CALL LINEAR (9,X2,DCD(1,I,J),X,DECD(J))
       IF (I .EQ. 2) CALL LINEAR (11,X4,DCD(1,I,J),X,DECD(J))
       IF (I .EQ. 3) CALL LINEAR (12,X6,DCD(1,I,J),X,DECD(J))
       IF (I .EQ. 4) CALL LINEAR (17,X8,DCD(1,I,J),X,DECD(J))
 103  CONTINUE
       CALL LINEAR( 5, TCP, DECD, TC, DLCD(I) )
 102  CONTINUE
       CALL LINEAR( 4, ZP, DLCD, Z, DELCD )
       RETURN
       END
C
C
C   SUBROUTINE CDMN FINDS THE MINIMUM DRAG COEFFICIENT
C   FOR 6E05 < RE < 5E06 FROM FIG. 2-53, MCCORMICK
       SUBROUTINE CDMN( Z, TC, CDMN1 )
       REAL DMDATA(12,6), MNDATA(6), Z3(6), TC2(12)
       DIMENSION CDM00(12), CDM02(12), CDM04(12), CDM06(12),
     &           CDM08(12), CDM10(12), CDM12(12)
       EQUIVALENCE (DMDATA(1,1), CDM00)
       EQUIVALENCE (DMDATA(1,2), CDM02)
       EQUIVALENCE (DMDATA(1,3), CDM04)
       EQUIVALENCE (DMDATA(1,4), CDM06)
       EQUIVALENCE (DMDATA(1,5), CDM08)
       EQUIVALENCE (DMDATA(1,6), CDM10)
C
       DATA Z3 / 0.0,.02,.04,.06,.08,.10 /
       DATA TC2  / .02,.04,.06,.08,.10,.12,.14,.16,.18,.20,.22,.24 /
       DATA CDM00 / .00465,.00478,.0049,.00515,.0055,.00565,.00578,
      &.0064,.0069,.0074,.00765,.00865 /
       DATA CDM02 / .005,.0051,.0054,.0058,.0062,.0067,.0069,
      &.0076,.0083,.0086,.0089,.0092 /
       DATA CDM04 / .0056,.00569,.00545,.00661,.0071,.00785,.0081,
      &.0084,.0088,.009,.0092,.00953 /
       DATA CDM06 / .0048,.0052,.006,.0065,.0073,.0081,.0083,
      &.0084,.0091,.0094,.0097,.0103 /
       DATA CDM08 / .0046,.0049,.0057,.0070,.00793,.00851,.0089,
      &.0092,.00973,.0103,.0107,.0111 /
       DATA CDM10 / .0085,.009,.00903,.00948,.00952,.010,.01003,
      &.01053,.01103,.01107,.01203,.01253 /
C
       DO 170  IE = 1,6
```

```
      CALL LINEAR( 12, TC2,  DMDATA(1,IE), TC, MNDATA(IE) )
 170  CONTINUE
      CALL LINEAR( 6, Z3, MNDATA, Z, CDMN1 )
      RETURN
      END
C
C
C    SUBROUTINE RECD FINDS THE EFFECT OF REYNOLDS NO. ON
C    MINIMUM DRAG COEFFICIENT -- FROM FIG. 2-54, MCCORMICK
      SUBROUTINE RECD( RE, ERE )
      DIMENSION R(9), ER(9)
      DATA R / 1.E  5, 1.5E  5, 2.E  5, 3.E  5, 4.E  5, 5.E  5, 6.E  5,
     &6.E  6, 8.E  6 /
      DATA ER   / 3.8,2.8,2.2,1.6,1.3,1.1,1.0,1.0,.95 /
C
      CALL LINEAR( 9, R, ER, RE, ERE )
      RETURN
      END
C
C
C
C    SUBROUTINE FDCOOR FINDS THE Y-DIMENSIONS OF A NACA 4-DIGIT AIRFOIL SECTION
C    IN ORDER TO CALCULATE THE MOMENT COEFFICIENT --
C    -- FROM EQS. 6.1-6.4, ABBOTT & VONDOENHOFF
      SUBROUTINE FDCOOR( YMEAN,NZRCLD,TCMAX,YU,YL,IO,N1 )
      REAL X2(14),YC(14),YMEAN(NZRCLD),SLOPE(14),THICK(14),
     &YU(10,10,14),YL(10,10,14)
      DATA X2 /0.,.025,.05,.1,.2,.3,.4,.5,.6,.7,.8,.9,.95,1.0 /
      XMEAN = 0.5
C
      NUMPTS = 14
      DO 2  I = 1,NUMPTS
      IF(X2(I) .GT. XMEAN) GO TO 1
      YC(I) =YMEAN(IO)/XMEAN**2*(2*XMEAN*X2(I)-X2(I)**2)
      GO TO 2
    1 YC(I) =YMEAN(IO)/(1-XMEAN)**2*(1-2*XMEAN+2*XMEAN*X2(I)-X2(I)**2)
    2 CONTINUE
      NUM = NUMPTS-1
      DO 6  JJ = 2,NUM
      SLOPE(JJ) = ( YC(JJ+1)-YC(JJ-1) )/( X2(JJ+1)-X2(JJ-1) )
    6 CONTINUE
      SLOPE(1) = ( YC(2)-YC(1) )/( X2(2)-X2(1) )
      SLOPE(NUMPTS) = ( YC(NUMPTS)-YC(NUM) )/( X2(NUMPTS)-X2(NUM) )
      DO 3  MM = 1,NUMPTS
      THICK(MM) =(TCMAX/.2)*(SQRT(X2(MM))*.2969-X2(MM)*.126
     &-X2(MM)**2*.3516+X2(MM)**3*.2843-X2(MM)**4*.1015)
      THETA = ATAN(SLOPE(MM))
      YU(IO,N1,MM) =YC(MM)+THICK(MM)*COS(THETA)
      YL(IO,N1,MM) =YC(MM)-THICK(MM)*COS(THETA)
    3 CONTINUE
      RETURN
      END
C    SUBROUTINE QCCM  FINDS THE MOMENT COEFFICIENT ABOUT
C    THE QUARTER-CHORD USING THE METHOD ON PAGE 72, ABBOTT & VONDOENHOFF
      SUBROUTINE QCCM( CMC4, YU, YL, IG, N, NN, MACH, CMLE, CL, N1, Z )
      REAL MACH
      DIMENSION  B1(14),X3(14),CMC4(10,10),CMLE(10,10,10),CL(10,10,10),
     &YU(10,10,14),YL(10,10,14)
      DATA X3 / 0.0,.025,.05,.1,.2,.3,.4,.5,.6,.7,.8,.9,.95,1.0 /
      DATA B1 / -.119,-.156,-.104,-.124,-.074,-.009,.045,.101,
     &.170,.273,.477,.786,3.026,-4.289 /
C
      CMC4(IG,N1) = 0.0
      DO 23  IGG = 1,14
      CMC4(IG,N1) = CMC4(IG,N1)+B1(IGG)*(YU(IG,N1,IGG)+YL(IG,N1,IGG))
   23 CONTINUE
      CMC4(IG,N1) = -(CMC4(IG,N1)-(.25*Z+.005))
      CMLE(NN,IG,N1) = CMC4(IG,N1)-.25*CL(NN,N,N1)
      CMLE(NN,IG,N1) = CMLE(NN,IG,N1)/SQRT(1-MACH**2)
      CMC4(IG,N1) = CMC4(IG,N1)/SQRT(1-MACH**2)
      RETURN
      END
C
C
```

```
C    SUBROUTINE FDCR FINDS THE DIMENSIONS OF A NACA
C    4-DIGIT AIRFOIL SECTION -- FROM EQS. 6.1-6.4, ABBOTT & VONDOENHOFF
      SUBROUTINE FDCR(YMEAN,NZRCLD,TCMAX,XU,XL,YU,YL,LERAD,
     &NUMACS,IO,N1)
      REAL LERAD(10,10),X2(53),YC(53),YMEAN(NZRCLD),SLOPE(53),
     &XU(10,10,53),XL(10,10,53),YU(10,10,53),YL(10,10,53)
      DATA X2 / 0.,.01,.02,.03,.04,.05,.06,.07,.08,.09,.1,.125,
     &.15,.175,.2,.225,.25,.275,.3,.325,.35,.375,.4,.425,.45,.475,.5,
     &.525,.55,.575,.6,.625,.65,.675,.7,.725,.75,.775,.8,.825,.85,
     &.875,.9,.91,.92,.93,.94,.95,.96,.97,.98,.99,1.0 /
      XMEAN = 0.5
C
      NUMACS = 53
      DO 7  I = 1,NUMACS
      IF(X2(I) .GT. XMEAN) GO TO 8
      YC(I) =YMEAN(IO)/XMEAN**2*(2*XMEAN*X2(I)-X2(I)**2)
      GO TO 9
    8 YC(I) =YMEAN(IO)/(1-XMEAN)**2*(1-2*XMEAN+2*XMEAN*X2(I)-X2(I)**2)
    9 CONTINUE
    7 CONTINUE
      NUM = NUMACS-1
      DO 16  JJ = 2,NUM
      SLOPE(JJ) = ( YC(JJ+1)-YC(JJ-1) )/( X2(JJ+1)-X2(JJ-1) )
   16 CONTINUE
      SLOPE(1) = ( YC(2)-YC(1) )/( X2(2)-X2(1) )
      SLOPE(NUMACS) = ( YC(NUMACS)-YC(NUM) )/( X2(NUMACS)-X2(NUM) )
      DO 17  MM = 1,NUMACS
      THICK =(TCMAX/.2)*(SQRT(X2(MM))*.2969-X2(MM)*.126
     &-X2(MM)**2*.3516+X2(MM)**3*.2843-X2(MM)**4*.1015)
      IF(MM .EQ. NUMACS) THICK = 0.0
      THETA = ATAN(SLOPE(MM))
      XU(IO,N1,MM) =X2(MM)-THICK*SIN(THETA)
      YU(IO,N1,MM) =YC(MM)+THICK*COS(THETA)
      XL(IO,N1,MM) =X2(MM)+THICK*SIN(THETA)
      YL(IO,N1,MM) =YC(MM)-THICK*COS(THETA)
   17 CONTINUE
      LERAD(IO,N1) =1.1019*TCMAX**2
      RETURN
      END
C
C
C    SUBROUTINE LINEAR INTERPOLATES LINEARLY BETWEEN POINTS
      SUBROUTINE LINEAR( NU, XIN, YIN, XOUT, YOUT )
      DIMENSION XIN(NU), YIN(NU)
      INTEGER  F
      NM1 = NU-1
      F = 1
C    TEST FOR OFF LOW END
      IF(XOUT .LT. XIN(1)) GO TO 110
      F = NM1
C    TEST FOR OFF HIGH END
      IF(XOUT .GT. XIN(NU)) GO TO 110
C    IN RANGE
      DO 120  II = 2,NM1
      F = II-1
      IF(XOUT .LE. XIN(II)) GO TO 110
  120 CONTINUE
      F = NM1
C    SLOPE INTERCEPT FORMULA
  110 CONTINUE
      IP1 = F+1
      SLP = (YIN(IP1)-YIN(F))/(XIN(IP1)-XIN(F))
      B2 = YIN(F)-XIN(F)*SLP
      YOUT = SLP*XOUT+B2
      RETURN
      END
C     SUBROUTINE AREA FINDS AREA , COORDINATES OF CENTROID ,
C     AND MOMENTS OF INERTIA ABOUT PRINCIPLE AXES
      SUBROUTINE AREA(XU,YU,XL,YL,AT,XREF,YREF,IMAJ,IMIN,IO,N1,CHORD )
      REAL IMAJ,IMIN
      DIMENSION AU(53),DXU(53),XMU(53),YMU(53),YPU(53)
      DIMENSION AL(53),DXL(53),XML(53),YML(53),YPL(53)
      DIMENSION A(53),DX(53),XM(53),YM(53),YP(53)
      DIMENSION XU(10,10,53),YU(10,10,53),XL(10,10,53),YL(10,10,53)
```

```
      DATA AUP,ALP,AP,XAU,XAL,XA,YAU,YAL,YA/9*0.0/
      IMAJ=0.0
      IMIN=0.0
      ISTEP=0
      NUMPTS=53
      DO 700 I=1,NUMPTS
      J=I+1
      IF(ISTEP.EQ.1)GO TO 702
      IF(I.EQ.NUMPTS-1)GO TO 720
      IF(YL(IO,N1,J+1).GT.0.0)GO TO 702
  720 DXU(I)=XU(IO,N1,J)-XU(IO,N1,I)
      DXL(I)=XL(IO,N1,J)-XL(IO,N1,I)
      XMU(I)=(XU(IO,N1,J)+XU(IO,N1,I))/2
      XML(I)=(XL(IO,N1,J)+XL(IO,N1,I))/2
      YMU(I)=(YU(IO,N1,J)+YU(IO,N1,I))/2
      YML(I)=ABS((YL(IO,N1,J)+YL(IO,N1,I))/2)
      YPU(I)=YMU(I)/2
      YPL(I)=-YML(I)/2
      AU(I)=DXU(I)*YMU(I)
      AL(I)=DXL(I)*YML(I)
      AUP=AUP+AU(I)
      ALP=ALP+AL(I)
      XAU=XAU+AU(I)*XMU(I)
      XAL=XAL+AL(I)*XML(I)
      YAU=YAU+AU(I)*YPU(I)
      YAL=YAL+AL(I)*YPL(I)
      A(I)=0.0
      GO TO 703
  702 XP1=(XU(IO,N1,I)+XL(IO,N1,I))/2
      XP2=(XU(IO,N1,J)+XL(IO,N1,J))/2
      DX(I)=XP2-XP1
      XM(I)=(XP1+XP2)/2
      YM(I)=(YU(IO,N1,J)-YL(IO,N1,J)+YU(IO,N1,I)-YL(IO,N1,I))/2
      YP(I)=(YU(IO,N1,J)+YL(IO,N1,J)+YU(IO,N1,I)+YL(IO,N1,I))/4
      A(I)=DX(I)*YM(I)
      XA=XA+A(I)*XM(I)
      YA=YA+A(I)*YP(I)
      AP=AP+A(I)
      ISTEP=1
  703 IF(I.EQ.NUMPTS-1)GO TO 704
  700 CONTINUE
  704 AT=AUP+ALP+AP
      XREF=(XAU+XAL+XA)/AT
      YREF=(YAU+YAL+YA)/AT
      CHORD=CHORD*12.0
      AT=AT*CHORD**2
      XREF=XREF*CHORD
      YREF=YREF*CHORD
      ISTEP=0
      K=NUMPTS-1
      DO 707 I=1,K
      IF(ISTEP.EQ.1)GO TO 706
      IF(A(I).GT.0.0)GO TO 706
      DIMIU=(DXU(I)*YMU(I)**3)/12+AU(I)*(YPU(I)-YREF)**2
      DIMIL=(DXL(I)*YML(I)**3)/12+AL(I)*(YPL(I)-YREF)**2
      IMIN=IMIN+DIMIU+DIMIL
      DIMAU=(YMU(I)*DXU(I)**3)/12+AU(I)*(XMU(I)-XREF)**2
      DIMAL=(YML(I)*DXL(I)**3)/12+AL(I)*(XML(I)-XREF)**2
      IMAJ=IMAJ+DIMAU+DIMAL
      GO TO 707
  706 DIMAJ=(YM(I)*DX(I)**3)/12+A(I)*(XM(I)-XREF)**2
      DIMIN=(DX(I)*YM(I)**3)/12+A(I)*(YP(I)-YREF)**2
      IMAJ=IMAJ+DIMAJ
      IMIN=IMIN+DIMIN
      ISTEP=1
  707 CONTINUE
      IMAJ=IMAJ*CHORD**4.0
      IMIN=IMIN*CHORD**4.0
      RETURN
      END
//$DATA
//$STOP
```

Appendix II

NACA 4-Digit Program Case

Input/Output

Input File

```
      DATA ALPHA / -10.0,-8.0,-6.0,-4.0,-2.0,0.0,2.0,4.0,6.0,8.0/
      DATA NUMALP / 10 /
      DATA CLD / 0.2 /
      DATA NZRCLD / 1 /
      DATA TC / 0.120 /
      DATA NUMTC / 1 /
      DATA CHORD /1.0/
      DATA MACH / 0.50/
      DATA NUMACH / 1 /
C   SET RE = 0.0 FOR CALCULATION OF RE BASED ON MACH, ALT AND CHORD
      DATA RE / 0.0/
      DATA ALT / 10000.0/
      DATA MCP / 3 /
      DATA ACP / 1 /
      DATA CAMP / 0 /
```

Output File

* NACA 4-DIGIT SERIES AIRFOIL COORDINATES *

CLD = 0.200000

(T/C)MAX = 0.120000

LERAD = 0.015867

X/C VALUE OF MAX. CAMBER = 0.500000

Y/C VALUE OF MAX. CAMBER = 0.016800

XUPPER	YUPPER	XLOWER	YLOWER
-0.000000	0.000000	0.000000	-0.000000
0.008880	0.017666	0.011120	-0.016335
0.018481	0.024866	0.021519	-0.022232
0.028210	0.030300	0.031790	-0.026389
0.038008	0.034796	0.041992	-0.029635
0.047854	0.038674	0.052146	-0.032290
0.057735	0.042099	0.062265	-0.034519
0.067642	0.045169	0.072358	-0.036420
0.077572	0.047950	0.082427	-0.038058
0.087521	0.050485	0.092479	-0.039478
0.097533	0.052811	0.102467	-0.040715
0.122455	0.057840	0.127545	-0.043140
0.147488	0.061960	0.152512	-0.044824
0.172570	0.065337	0.177430	-0.045933
0.197688	0.068081	0.202311	-0.046577
0.222836	0.070274	0.227164	-0.046838
0.248005	0.071979	0.251995	-0.046779
0.273190	0.073243	0.276810	-0.046447
0.298387	0.074107	0.301613	-0.045884
0.323592	0.074604	0.326408	-0.045120
0.348801	0.074762	0.351199	-0.044186
0.374011	0.074604	0.375989	-0.043104
0.399220	0.074153	0.400780	-0.041897
0.424425	0.073425	0.425575	-0.040581
0.449625	0.072438	0.450375	-0.039174
0.474817	0.071205	0.475183	-0.037689
0.500000	0.069740	0.500000	-0.036140
0.525172	0.068053	0.524828	-0.034538
0.550333	0.066155	0.549667	-0.032891
0.575480	0.064054	0.574520	-0.031210
0.600613	0.061757	0.599387	-0.029502
0.625731	0.059273	0.624269	-0.027773
0.650833	0.056605	0.649167	-0.026029
0.675918	0.053758	0.674082	-0.024274
0.700984	0.050738	0.699015	-0.022514
0.726033	0.047546	0.723967	-0.020750
0.751061	0.044185	0.748939	-0.018985
0.776070	0.040657	0.773930	-0.017221
0.801057	0.036962	0.798943	-0.015458
0.826022	0.033100	0.823978	-0.013696
0.850964	0.029071	0.849036	-0.011935
0.875883	0.024873	0.874117	-0.010173
0.900763	0.020505	0.899237	-0.008409
0.910728	0.018708	0.909272	-0.007701
0.920674	0.016885	0.919326	-0.006993
0.930616	0.015033	0.929384	-0.006283
0.940554	0.013152	0.939446	-0.005572
0.950487	0.011243	0.949513	-0.004859
0.960416	0.009305	0.959584	-0.004144
0.970340	0.007338	0.969660	-0.003426
0.980260	0.005341	0.979740	-0.002706
0.990174	0.003314	0.989826	-0.001984
1.000000	0.000000	1.000000	-0.000000

Output File

```
* NACA 4-DIGIT SERIES AIRFOIL DATA BANK *

             CLD =      0.200000

       (T/C)MAX =      0.120000

       MACH NO. =      0.500000

   REYNOLDS NO. =      0.274529E 07

            AREA =     11.828390   IN**2
      XCENTRIOD =      5.048587   IN
      YCENTRIOD =      0.153324   IN

          IMAJOR =   36573.010   IN**4
          IMINOR =   35.0840600  IN**4

            CMC4 =     -0.050110
```

ALPHA	CL	CD	CMLE
-10.000000	-0.960685	0.011524	0.227216
-8.000000	-0.728548	0.010441	0.160204
-6.000000	-0.496411	0.009357	0.093192
-4.000000	-0.264274	0.008250	0.026179
-2.000000	-0.032137	0.007105	-0.040833
0.000000	0.200000	0.006728	-0.107845
2.000000	0.432137	0.006530	-0.174857
4.000000	0.664274	0.009618	-0.241869
6.000000	0.896411	0.013376	-0.308881
8.000000	1.128548	0.017133	-0.375893

III NACA-16 AIRFOIL DATA BANK

1. Introduction

The NACA 16-series airfoils were designed for use at transonic Mach numbers, and are particularly adaptable to the outer radii of propeller systems. These airfoils were designed to raise the Mach number at which the "compressibility burble" appears, and hence control the onset of drag divergence. This problem was originally discovered in the early 1940's when the requirement for higher aircraft velocities was realized. The reduction in drag was attained by decreasing the induced velocity near the leading edge of the airfoil and increasing the induced velocity over the rear segment of the airfoil, which resulted in a constant value of the pressure distribution over the majority of the wing section.

The NACA-16 series airfoil is designated by 16-XXX, with the first digit representing the lift coefficient at zero degree angle-of-attack (C_{ld}), and the last two digits designating the maximum thickness in percent of chord of the airfoil.

The computer program for the NACA 16-series airfoil databank, contained in Appendix I, was derived from publications by Cooper[1] and the Curtiss-Wright Corporation[2]. The program uses tables and plots from these papers to compute the coefficients of lift, drag, and moment about the quarter chord. Values of these aerodynamic coefficients from the existing databank were compared with the output from the airfoil analysis computer code of Smetana et.al.[3] and found to be acceptable as indicated in Table I, with an average deviation of 1.93%.

Limits exist with the NACA 16-series airfoil data bank computer program. Flags have been installed where a limitation is exceeded, and appear in the "Limitations" category in the printed output. These limitations will be discussed in detail in the following Sections.

2. Input.

The code has been arranged to compute up to 15 angles-of-attack and 15 different Mach numbers with properly dimensioned arrays. Essentially, the airfoil is dictated by the specification of the design lift coefficient (C_{l_d}), the maximum thickness to chord ratio ((t/c)max), and the airfoil chord in feet. A list of input parameters is described in Table II and provided in Appendix II for the sample case. Other input parameters dictate the amount of computer output desired, including compressibility effects and other factors to be discussed later.

3. Main Program.

The main program is designed as an operating system to route the variables to the various subroutines described in the ensuing Sections. The output is passed back to the main program and output.

4. Subroutine ATMCON.

ATMCON calculates the temperature, pressure, speed of sound, density, and viscosity for a specified altitude using the empirical equations of Minzer, et.al.[3] as given by Anderson[4].

These equations have been curve fit from the available data of the ARDC 1959 standard atmosphere[3], and divide the atmosphere into two regions, i.e., from sea level to 11,000 meters, and 11,000 to 25,000 meters. These equations are given as:

<u>Sea level to 11,000 meters.</u>

$$\text{Temp} = 288.16 - 0.0065\ h \qquad \text{III-1}$$

$$P = (101325)/(1/(\text{Temp}/288.16))^{-5.2457} \qquad \text{III-2}$$

<u>11,000 meters to 25,000 meters.</u>

$$\text{Temp} = 216.66 \qquad \text{III-3}$$

$$P = (22{,}700)\exp(0.0001547(h-11{,}000)) \qquad \text{III-4}$$

where h is in meters, Temperature is in °K, and pressure is in N/m^2. The values of P and Temp are converted by;

$$\text{Temp} = (\text{Temp} - 273.15)\ 9/5 + 491.67 \qquad \text{III-5}$$

$$P = 2116.2\ P/101325 \qquad \text{III-6}$$

where Temp and P are now in units °R and lbs/ft^2, respectively. Values of density, viscosity, and speed of sound are then calculated by:

$$\text{Density} = (\text{Pressure})/(1718)(\text{Temp}) \qquad \text{III-7}$$

$$\text{Viscosity} = 3.5 \times 10^{-7} \qquad \text{III-8}$$

$$\text{Speed of Sound} = \sqrt{(403.2)(\text{Temp})/0.3047} \qquad \text{III-9}$$

where density is in $lb\text{-}ft^2/sec^4$, viscosity in $lb\text{-}sec/ft^2$, and speed of sound in ft/sec.

5. Subrutine CLCD

Subroutine CLCD calculates the section lift and drag coefficients for a NACA-16 series airfoil. The database for this subroutine has been taken from graphical descriptions of data as found in Cooper[1].

The lift curve slope ($dC_l/d\alpha$) is computed for the case of subsonic or supersonic Mach number. For the subsonic case, compressibility effects are taken into account by the application of the Prandtl-Glauert factor(1). The lift-curve slope is then found by one of the following equations:

Incompressible Lift Curve Slope

$$\frac{dC_l}{d\alpha} = \frac{.1096(1-(t/c)max)}{\sqrt{1-(t/c)max^2}} \qquad (deg^{-1}) \qquad \text{III-10}$$

Compressible Subsonic Lift Curve Slope

$$\frac{dC_l}{d\alpha} = \frac{.1096(1-(t/c)max)}{\sqrt{1-(M+(t/c)max^2)}} \qquad (deg^{-1}) \qquad \text{III-11}$$

Supersonic Lift Curve Slope

$$\frac{dC_l}{d\alpha} = \frac{.0698}{\sqrt{M^2 - 1}} \qquad (deg^{-1}) \qquad \text{III-12}$$

and the lift coefficient, utilizing the lift-curve slope is found by:

$$C_l = \frac{dC_l}{d\alpha} \alpha \qquad \text{III-13}$$

The drag coefficient can be obtained from an algorithm contained in Cooper(1) in which the drag is characterized by the sum of four components, i.e., the basic drag coefficient (C_{do}), the increment due to lift (C_{dl}), the increment due to camber (C_{dd}), and the increment due to skin friction (C_{df}). Using

Figure 1 and knowing the difference between the lift coefficient and the design lift coefficient, and the corrected airfoil section Mach number (M_s) given by:

$$M_s = \frac{M_x}{0.9 - (t/c)max} \qquad \text{III-15}$$

the parameter $\Delta C_d/(C_l - C_{ld})^2$ is found. The drag due to lift (C_{dl}) may then be calculated by:

$$C_{dl} = \frac{\Delta C_d}{(C_l - C_{ld})^2} (C_l - C_{ld})^2 \qquad \text{III-16}$$

The skin friction drag (C_{df}) is obtained by specifying from the Reynolds number and the radial blade location (X=r/R). The radial location on the propeller blade indicated a strong effect on the extent of laminar run of each airfoil section, and has been quantized by Cooper[1](Figure 2). Thus the skin friction drag coefficient (C_{df}) is found graphically in Figure 3, and curve fit for the airfoil databank.

The drag due to camber (C_{dd}) represents the increase in the minimum basic drag of cambered NACA 16-series airfoils over that of an uncambered section as given in Figure 4. The data were obtained from two-dimensional NACA tests which extended to Mach 0.8. Above Mach 0.8 and in supersonic flow, the effects of camber are known to be small and C_{dd} approaches zero.

Finally, the basic drag coefficient (C_{do}) is given in Figure 5 as a function of (t/c)max and section Mach number (M_x). This relationship was obtained by Hoerner[5] from low speed wind tunnel tests of NACA-16 series airfoil sections.

These four drag contributions are summed to obtain the total drag coefficient of the airfoil section:

$$C_d = C_{do} + C_{df} + C_{dl} + C_{dd} \qquad \text{III-17}$$

6. Moment Coefficient

The moment coefficent is obtained from tables acquired from Lindsey, et.al.[6]. These tables were generated from the results of wind tunnel tests of 24 related airfoil sections over a Mach number range of 0.3 to 0.75. A typical plot is shown in Figure 6. The tables are arranged in matrix form for C_{ld} values of 0.0, 0.1, 0.3, and 0.5, at Mach numbers of 0.3, 0.45, 0.6, 0.7, and 0.75 with thickness ratios of 0.02, 0.06, 0.09, 0.12, 0.15, 0.21 and 0.30. These data are contained in Function Subroutines designated CMXXX, where a Lagrangian interpolation scheme obtains the desired airfoil quarter chord moment coefficient from the available information. However, this value can easily be transformed to the moment coefficient about the airfoil leading edge by:

$$C_{mle} = C_{mqc} - 0.25\ C_l \qquad \text{III-8}$$

7. Subroutine N16COOR

The airfoil coordinates and other pertinent airfoil information is computed, if desired, in this subroutine where:

$$\text{L.E. radius} = \frac{0.489\ (t/c)max^2}{Chord} \qquad \text{III-19}$$

$$Area = 0.7396(1 + 0.00544\ C_{ld}^2)(t/c)max\ Chord \qquad \text{III-20}$$

$$M_x = 0.03335(1 + 0.00196\ C_{ld}^2)\ C_{ld}\ (t/c)max\ Chord^2 + \qquad \text{III-21}$$
$$0.01775(1 + 0.1332\ C_{ld}^2)\ C_{ld}\ (t/c)max^3$$

$$M_y = 0.3569(1 + 0.00458\ C_{ld}^2)(t/c)max\ Chord^2 \qquad \text{III-22}$$

$$I_x = 0.04476(1 - 0.00182 C_{ld}^2)(t/c)max^3\ Chord + \qquad \text{III-23}$$
$$0.00009358(1 + 0.02013\ C_{ld}^2)\ C_{ld}^2\ (t/c)max\ Chord^3$$

$$I_y = 0.04221(1 + 0.01287\ C_{ld}^2)\ (t/c)max\ Chord^3 \qquad \text{III-24}$$

The moments, M_x and M_y, and the moments of inertia I_x and I_y are computed about the respective axes. The airfoil coordinates are computed from empirically derived Tables that define the airfoil shape along with the given (t/c)max and given C_{ld}. The equations are given as:

$$A = C_1 C_{ld}\ Chord + C_2\ C_{ld}\ (t/c)max^2/Chord \qquad \text{III-25}$$

$$B = C_3\ (t/c)max + C_4 C_{ld}^2\ (t/c)max \qquad \text{III-26}$$

with the coefficients C_1, C_2, C_3, and C_4 specified in Table III as a function of chord location. The coordinates are then calcualted by:

$$Y_u = \frac{2\ A}{Chord} \qquad \text{III-27}$$

$$Y_l = \frac{A - B}{Chord} \qquad \text{III-28}$$

where Y_u is the upper airfoil coordinate, and Y_l is the airfoil lower coordinate for a given x/c location.

8. Limitations

As stated earlier, some limitations exist in the computer program, and when exceeded, flags are contained in the program output to indicate to the User what value has been exceeded. It is to be noted that a Mach number of 0.0 is not allowed, and the program has difficulty handling negative angles of attack of large magnitude at high Mach numbers for thick airfoils. The flags appear as:

(a) "T/C= 30 IS GREATER THAN (T/C)MAX= 26 FOR THE LIFT CURVE SLOPE"

(b) "(CL-CLD)=.9 IS GREATER THAN (CL-CLD)(MAX)=.8 FOR DRAG DUE TO LIFT"

(c) "CLD= .8 IF GREATER THAN CLDMAX= .6 FOR DRAG DUE TO CAMBER"

(d) "T/C= .40 IS GREATER THAN (T/C)MAX= .30 FOR THE BASIC DRAG"

(e) "MACH NO.= .95 IS GREATER THAN (T/C)MAX=.35 FOR THE MOMENT COEFFICIENT"

(f) "T/C= .40 IS GREATER THAN (T/C)MAX= .35 FOR THE MOMENT COEFFICIENT"

(g) "CL= 1.6 IS GREATER THAN CLMAX= 1.3 FOR THE MOMENT COEFFICIENT"

(h) "CLD=.9 OF GREATER THAN CLDMAX=.8 FOR THE MOMENT COEFFICIENT"

(i) "ANGLE= 10.0 IS GREATER THAN MAX ANGLE= 9.0"

(j) "MACH NO.= .95 IS GREATER THAN MACH NO.(MAX)= .9 FOR SUBSONIC SPEED"

9. Sample Case

A sample case with the corresponding input and output is provided in Appendix II to indicate how the NACA 16-series airfoil databank computer code may be utilized. The complete output selection for the sample case was chosen to show the full capabilities of the databank code.

REFERENCES

1. Cooper, J.P., "The 'Linearized Inflow' Propeller Strip Analysis", WADC TR 56-615, February 1957.

2. Enos, T., and Borst, H.V., "Propeller Performance Analysis Aerodynamic Characteristics NACA 16 Series Airfoils" - Part I and II, December 1948.

3. Smetana, F.O., Summey, D.C., Smith, N.S., and Carden, R.K., "Light Aircraft Lift, Drag, and Moment Prediction - A Review and Analysis", NASA CR-2523, May 1975.

4. Minzner, R.A., Champoin, K.S.W., and Pond, H.L., "The ARDC Model Atmosphere", Air Force Cambridge Research Center Report No. TR-59-267, 1959.

5. Anderson, Jr.,J.D., Introduction to Flight, McGraw-Hill Book Company, 1978.

6 Hoerner, S. F., Aerodynamic Drag, Otterbien Press, Dayton, Ohio, 1951.

7. Lindsey, W. F., Stevenson, D.B., and Daley, B.N., "Aeronautical Characteristics Of 24 NACA 16-Series Airfoils at Mach Numbers Between 0.3 and 0.8", NACA TN 1546, December 1947.

8. Abbott,I.H., and von, Doenhoff, A.E., Theory of Wing Sections, Dover Publications, 1959.

Table I. Comparison Cases for NACA-16 Airfoil Data Bank.

$(t/c)_{max}$	Mach No.	α (deg)	Actual Values C_l	Actual Values C_d	NACA-16 Values C_l	NACA-16 Values C_d	$\Delta\%C_l$	$\Delta\%C_d$
				(C_{ld} = 0.1)				
0.04	0.45	0	0.1147	0.0056	0.1146	0.0008	1.31	-31.50
0.04	0.45	2	0.3583	0.0071	0.3560	0.0107	0.64	-33.88
0.06	0.45	0	0.1100	0.0005	0.1160	0.0008	-5.22	-30.72
0.06	0.45	2	0.3527	0.0081	0.3556	0.0111	-0.81	-27.10
0.06	0.70	0	0.1400	0.0075	0.1536	0.0174	-8.86	-56.59
0.06	0.70	2	0.5181	0.0159	0.4706	0.0221	10.09	-28.17
0.09	0.45	0	0.1007	0.0065	0.1184	0.0090	-14.87	-28.74
0.09	0.45	2	0.3359	0.0090	0.3553	0.0116	-5.47	-21.20
0.09	0.70	0	0.1330	0.0083	0.1625	0.0238	-18.14	-65.09
0.09	0.70	2	0.4690	0.1914	0.4878	0.0287	-3.85	-33.52
				C_{ld} = 0.3				
0.02	0.70	0	0.4761	0.0072	0.4322	0.0073	10.14	-2.16
0.02	0.70	2	0.7842	0.0139	0.7418	0.0153	5.71	-8.47
0.04	0.45	0	0.3135	0.0139	0.7418	0.0073	-8.82	-23.45
0.04	0.45	2	0.5741	0.0093	0.5852	0.0105	-2.42	-11.73
0.04	0.70	0	0.4691	0.0070	0.4456	0.0074	5.26	-6.88
0.04	0.70	2	0.7911	0.0161	0.7585	0.0160	4.30	0.59
0.06	0.45	0	0.3135	0.0050	0.3482	0.0075	-9.95	-33.18
0.06	0.45	2	0.5599	0.0098	0.5877	0.0180	-4.73	-9.20
0.06	0.70	0	0.4621	0.0088	0.4608	0.0078	0.28	11.82
0.06	0.70	2	0.7981	0.0182	0.7778	0.1711	2.61	6.45
0.09	0.45	0	0.2855	0.0065	0.3550	0.0079	-19.57	-17.65
0.09	0.45	2	0.5262	0.0110	0.5920	0.0112	-11.10	-2.37
0.09	0.70	0	0.4060		0.4873	0.0086	-16.68	
0.09	0.70	2	0.7415	0.0182	0.8127	0.0191	-8.68	-5.13

Table II. NACA-16 Series Input List.

M	Mach Number
ANGLE	Angle of Attack
ALTUDE	Geometric Altitude (in feet)
CHORD	Chord (feet)
TC	Maximum Thickness to Chord ratio
CLD	Design Lift Coefficient
ICL	Lift Coefficient Parameter 0 = Incompressible Lift Coefficient 1 = Compressible Lift Coefficient
ICD	Drag Coefficient Parameter 0 = Incompressible Drag Coefficient 1 = Compressible Drag Coefficient
X	Radial Location on the Propeller (r/R)
NUMACH	Number of Mach Numbers
NUMALP	Number of Alphas
IFORM	Output Format Control
MP	Moment Coefficient Parameter 0 = No Moment Computed 1 = Moment Coefficient about Leading Edge 2= Moment CoefficientaboutQuarter Chord
L	Airfoil Coordinates Parameter 0 = No Coordinates Computed 1 = Airfoil Coordinates Computed

Table III. Airfoil Coordinate Coefficients.

Chordwise Station	C_1	C_2	C_3	C_4
1	0.00930	0.12720	0.15044	0.00639
2	0.01580	0.09653	0.20911	0.00574
3	0.02587	0.06600	0.28811	0.00440
4	0.03982	0.03473	0.38867	0.00237
5	0.04861	0.01461	0.45144	0.00103
6	0.05356	0.00394	0.48789	0.00025
7	0.05516	0.00000	0.50000	0.00000
8	0.65356	0.00447	0.48622	0.00025
9	0.04861	0.01895	0.43911	0.00100
10	0.03982	0.04400	0.34989	0.00021
11	0.02587	0.05961	0.20978	0.00321
12	0.0158	0.05469	0.11789	0.00324

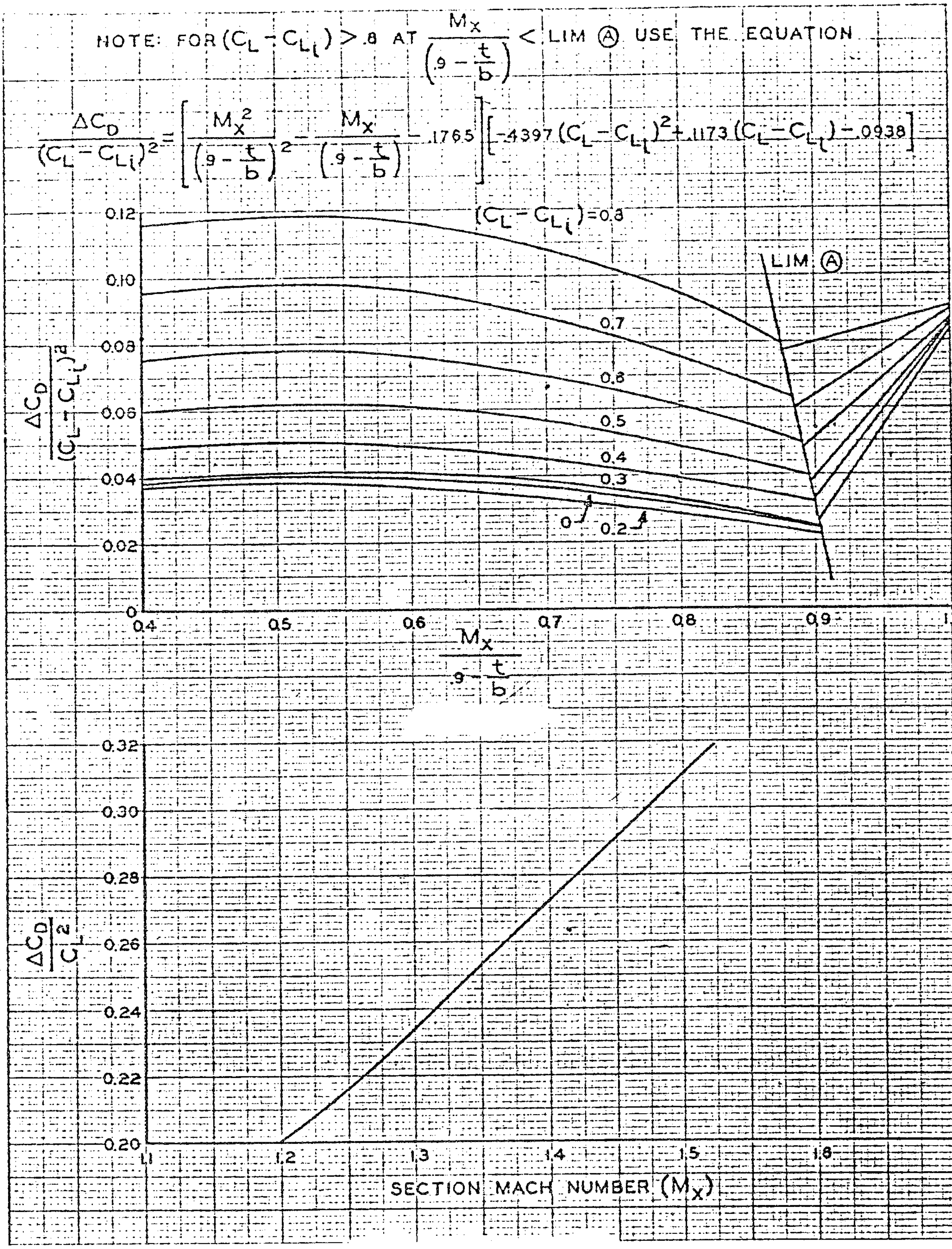

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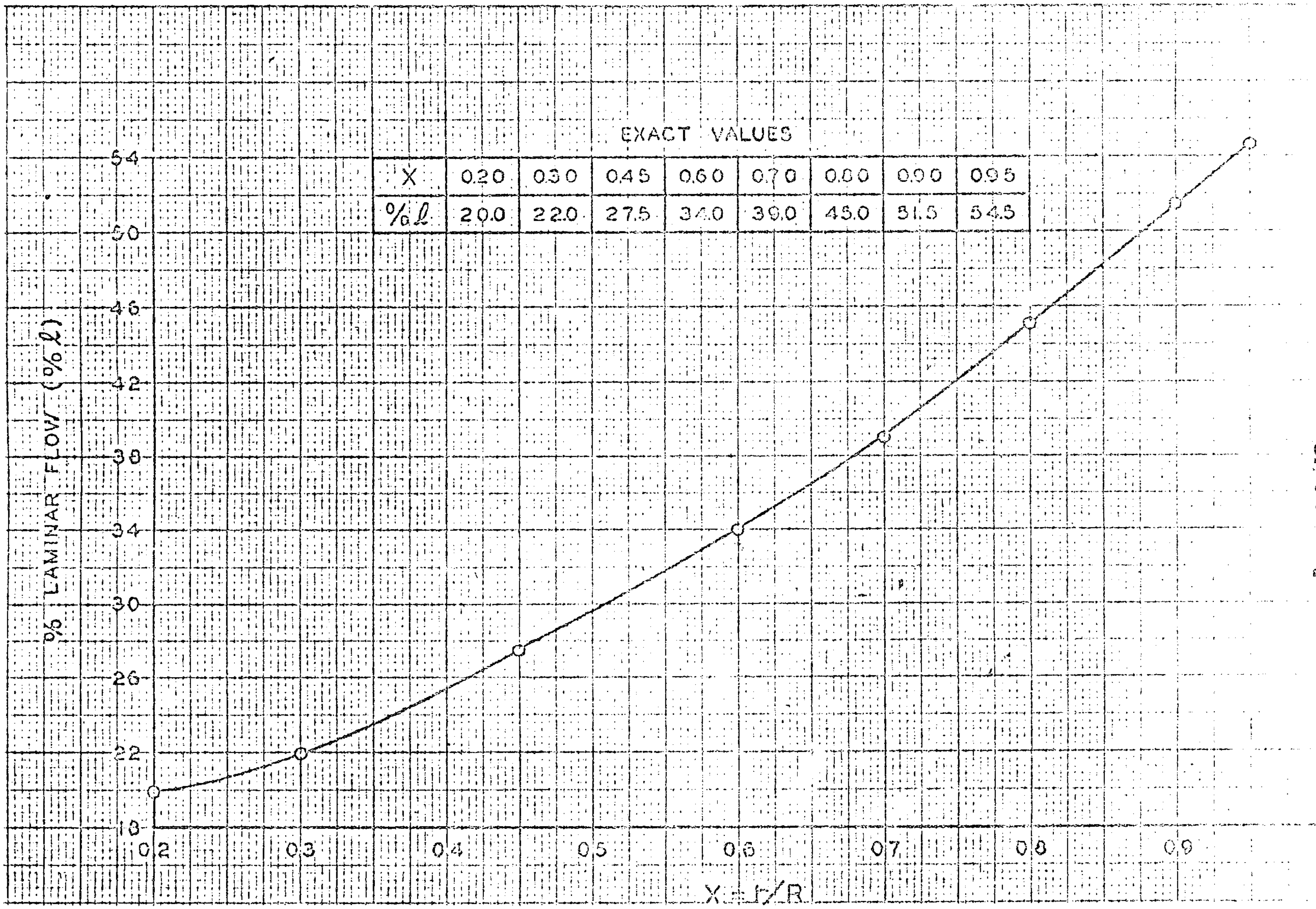
Figure 1. Drag Due to Lift for Subsonic and Supersonic Mach Numbers.



X	0.20	0.30	0.45	0.60	0.70	0.80	0.90	0.95
%ℓ	20.0	22.0	27.5	34.0	39.0	45.0	51.5	54.5

Figure 2. Percentage Laminar Flow Along Blade Span.

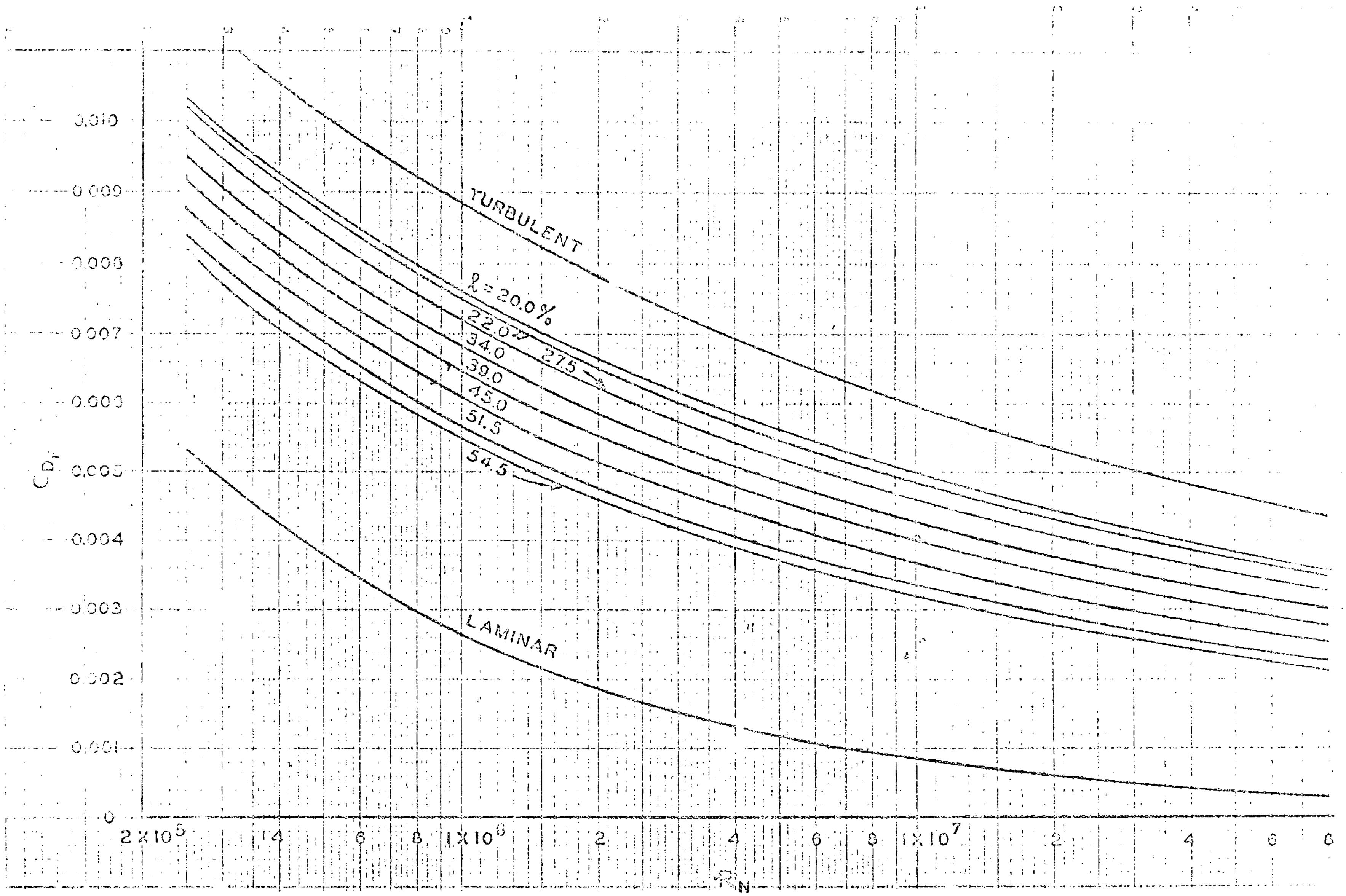


Figure 3. Friction Drag Coefficient (C_{Df}) versus Reynolds Number.

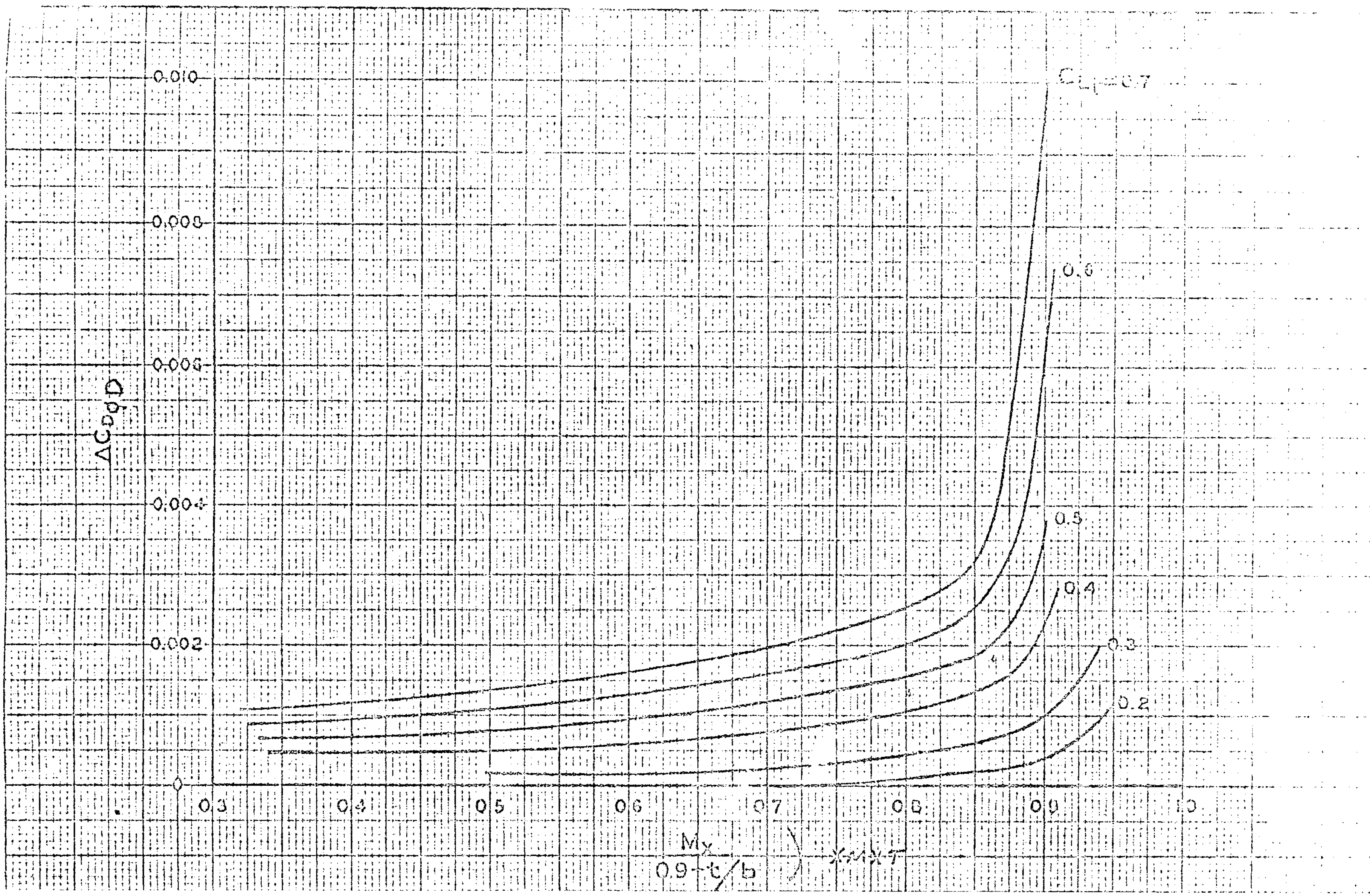


Figure 4. Increase in Basic Drag Due to Camber.

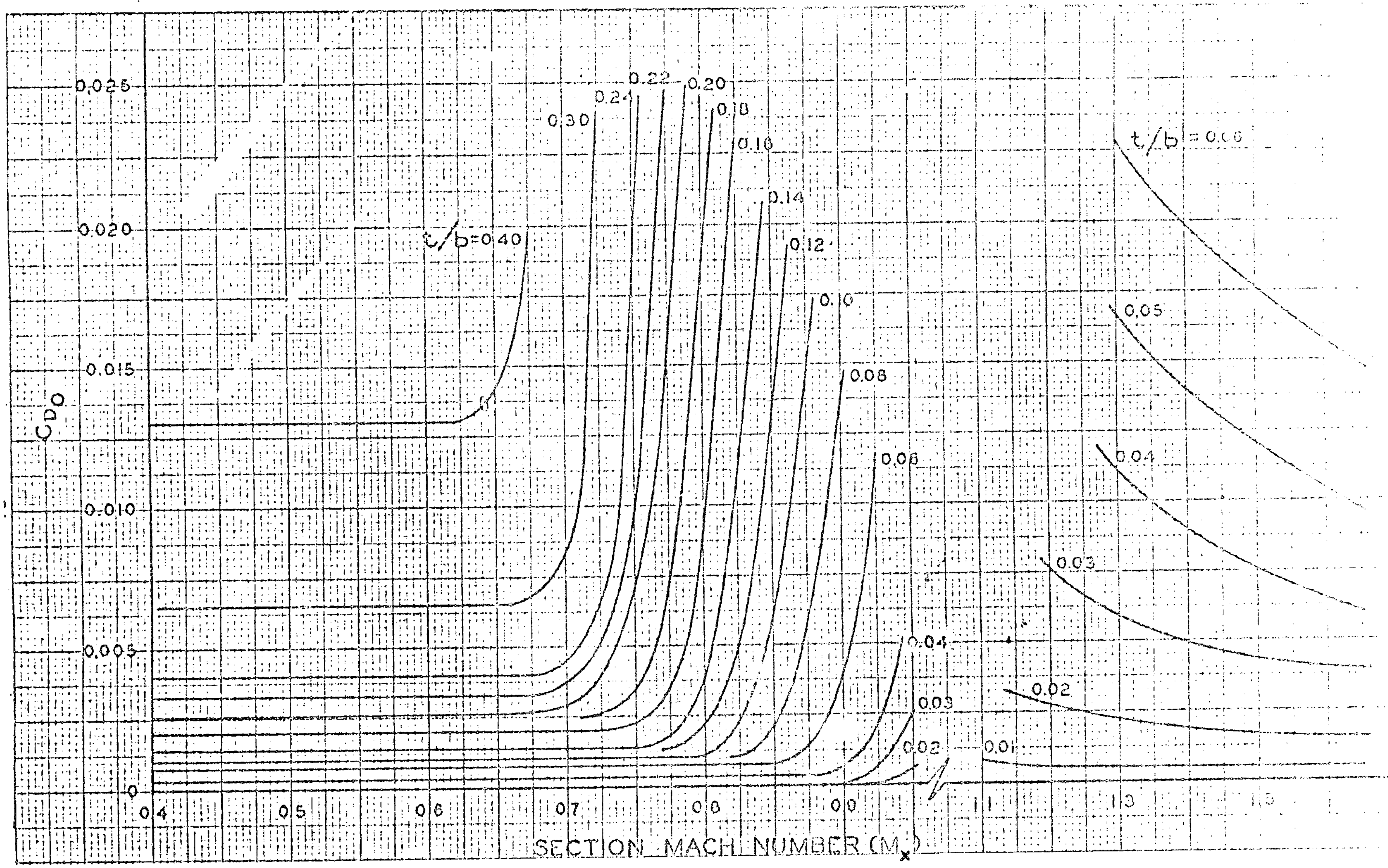


Figure 5. Basic Section Drag Coefficient.

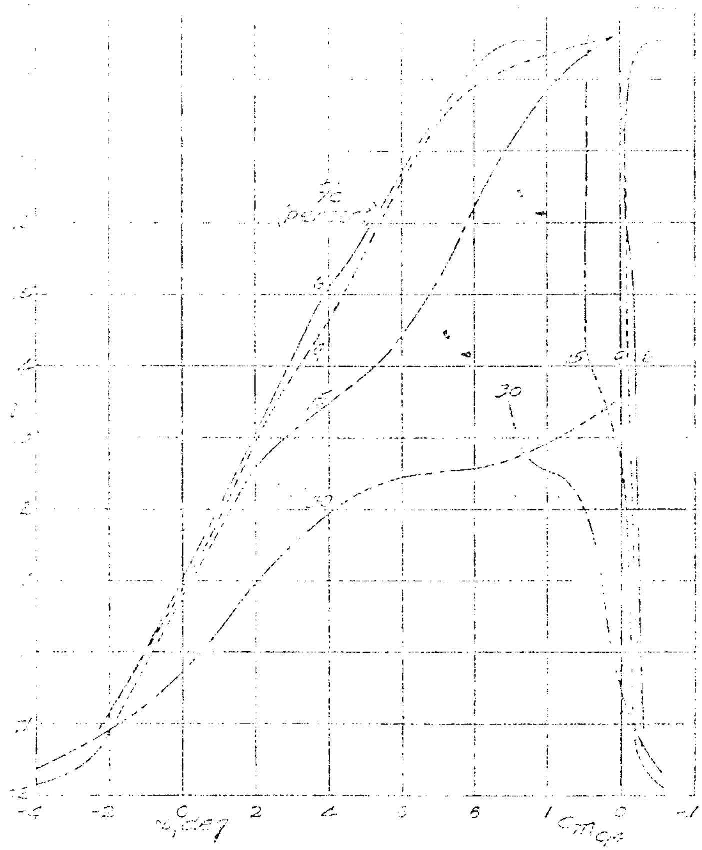


Figure 6. Lift Coefficient versus Angle-of-Attack and Moment Coefficient for $(t/c)_{max}$ ratios from 6% to 30%.

Appendix - I

NACA 16-Series Program Listing

```
//NACA16  JOB (R205,011C,S02,002,A7),'CAMBA'
//*XBM WATFIV
C
C
C
C
C
C      ***********************************************************
C      *                                                         *
C      *       PROGRAM TO CALCULATE THE LIFT, DRAG, AND          *
C      *                                                         *
C      *       MOMENTS FOR NACA 16-SERIES AIRFOILS               *
C      *                                                         *
C      ***********************************************************
C
C
C
C       THIS PROGRAM CALCULATES THE LIFT COEFFICIENTS DRAG COEFFI-
C       CIENTS, LIFT-TO-DRAG RATIOS, AND MOMENT COEFFICIENTS FOR
C       NACA 16-SERIES AIRFOILS. IT IS WRITTEN IN FORTRAN G-1,
C       ORIGANALLY FOR USE ON A HARRIS /6 COMPUTER. THE USER WILL
C       HAVE TO DEVLEOP A ROUTINE FOR READING IN THE INPUT
C       THAT IS COMPATIBLE WITH HIS OR HER SYSTEM. SOME LIM-
C       ITATIONS DO EXIST IN THE PROGRAM. A MACH NUMBER OF
C       0.0 IS NOT ALLOWABLE. ALSO, THE PROGRAM HAS TROUBLE
C       HANDLING NEGATIVE ANGLES OF ATTACK OF LARGE MAGNITUDE
C       AT HIGH MACH NUMBERS FOR THICK AIRFOILS.
C
C
C
C                INPUT LIST
C
C      ICD    = DRAG COEFFICIENT COMPRESSIBILTY CHECK FACTOR
C             = 0, GIVES INCOMPRESSIBLE DRAG COEFFICIENT
C             = 1, GIVES COMPRESSSIBLE DRAG COEFFICIENT
C
C      ICL    = LIFT COEFFICIENT COMPRESSIBILITY CHECK FACTOR
C             = 0, FOR AN INCOMPRESSIBLE LIFT COEFFICIENT
C             = 1, FOR A COMPRESSIBLE LIFT COEFFICIENT
C
C      IFORM  = CHECK PARAMETER WHICH CONTROLS FORMAT OF OUTPUT
C             = 0, GIVES ALL OF THE INCREMENTS IN THE DRAG
C             = 1, GIVES TABULAR OUTPUT OF CL AND CD AT EACH ALPHA
C                  ONE TABLE FOR EACH MACH NUMBER
C
C      NUMALP = NUMBER OF ALPHAS SPECIFIED (INTERGER)  UP TO 15
C
C      NUMACH = NUMBER OF MACH NUMBERS (INTEGER) UP TO 15
C
C      CLD    = DESIGN LIFT COEFFICIENT
C
C      TC     = THICKNESS TO CHORD RATIO
C
C      CHORD  = CHORD LENGTH (FEET)
C
C      ALTUDE = ALTITUDE (FEET)
C
C      M      = MACH NUMBER(S)
C
C      ANGLE  = ANGLE(S) OF ATTACK REFERENCED FROM THE LONGEST CHORD (DEGREES)
C
C      X      = RADIAL LOCATION
C
C      MP     = MOMENT COEFFICIENT PARAMETER
C             = 0, IF THE MOMENT COEFFICIENTS ARE NOT DESIRED
C             = 1, FOR THE MOMENT COEFFICIENT ABOUT THE LEADING EDGE
C             = 2, FOR THE MOMENT COEFFICIENT ABOUT THE QUARTER CHORD
C
C      L      = AIRFOIL COORDINATES PARAMETER
C             = 0, IF THE COORDINATES ARE NOT DESIRED
C             = 1, GIVES THE AIRFOIL SECTION COORDINATES AND ITS
C                  MOMENTS OF INERTIA
C
C
```

```
C
C              SUBROUTINE ATMCON
C
C       THIS SUBROUTINE IS VERY STRAIGHT FORWARD. GIVEN AN ALTITUDE, THE
C       SUBROUTINE CALCULATES THE TEMPERATURE, PRESSURE, DENSITY, VISCOSITY,
C       AND SPEED OF SOUND AT THAT ALTITUDE.
C
C
C
C              SUBROUTINE N16COR
C
C       THIS SUBROUTINE CALCULATES THE DIMENSIONS AND SECTION PROPERTIES
C       FOR A (SOLID SECTION) NACA 16-SERIES AIRFOIL SECTION FOR ANY
C       GIVEN THICKNESS, CHORD, AND DESIGN LIFT COEFFICIENT.  IF A
C       DESIGN LIFT COEFFICIENT IS NOT KNOWN BUT THE AREA, TC, AND
C       CHORD IS, THEN THE CLD WILL BE OUTPUT.  THE ROUTINE ALSO CAL-
C       CULATES THE MOMENT OF INERTIA FOR THE MAJOR (X) AND MINOR
C       (Y) AXES.  SEVERAL OTHER PROPERTIES OF THE NACA 16-SERIES ARE
C       CALCULATED, BUT ARE NOT OUTPUT UNLESS DESIRED.  THEY ARE
C       DEFINED BELOW.  ALSO NOTE THAT THE COORDINATES ARE NON-DIMEN-
C       SIONAL WITH RESPECT TO THE CHORD, AND THE X UPPER AND LOWER
C       ARE THE SAME.
C            LERAD  = LEADING EDGE RADIUS OF AIRFOIL
C            TERAD  = TRAILING EDGE RADIUS OF AIRFOIL
C            MY     = MOMENT ABOUT THE Y AXIS
C            MX     = MOMENT ABOUT THE X AXIS
C            IYC    = MOMENT OF INERTIA ABOUT Y CENTROIDAL AXIS
C            IXC    = MOMENT OF INERTIA ABOUT X CENTROIDAL AXIS
C
C
C
C                   SUBROUTINE CLCD
C
C
C
C      SUBROUTINE CLCD CALCULATES THE SECTION LIFT AND DRAG COEFFICIENTS FOR A
C      NACA 16-SERIES AIRFOIL. THE DATA BASE FOR THIS SUBROUTINE IS FROM:
C      COOPER, J. L., "THE 'LINEARIZED INFLOW' PROPELLER ANALYSIS" WADC TR 56-516,
C      1957. THE EQUATIONS AND GRAPHS CONTAINED IN THIS REPORT FORM THE BASIS
C      FOR ALL FURTHER DISCUSSION.
C
C
C                    CALCULATION OF CL   (SEE COOPER, P. 14)
C
C        A.  FOR SUBSONIC SECTION VELOCITIES:
C
C         CL= ALPHA*DCLDA    WHERE:
C
C         DCLDA=.1096*(1-XTC)/SQRT(1-XTC**2)
C         AND ALPHA IS SPECIFIED IN INPUT
C
C        B. FOR SUPERSONIC SECTION VELOCITIES:
C
C        DCLDA=.0698/SQRT(XM**2-1)
C        XM= LOCAL MACH NUMBER
C
C        AND CL=ALPHA*DCLDA
C
C
C
C
C
C                CALCULATION OF CD
C
C       THE DRAG COEFFICIENT IS CALCULATED IN FOUR INCREMENTS: BASIC DRAG
C       COEFFICIENT(CDZERO);THE INCREMENT DUE TO LIFT(CDLIFT); THE INCREMENT
C       DUE TO CAMBER(CDCAMB);AND THE INCREMENT DUE TO SKIN FRICTION(CDFRIC).
C
C
C
C       BASIC DRAG COEFFICIENT:
C
C
C       DATA FOR CALCULATION OF CDZERO IS TAKEN FROM FIG 12, P.31 IN COOPER.
```

```
C     THIS IS A PLOT OF CDZERO -VS- MACH NUMBER AS A FUNCTION OF THICKNESS.
C     GIVEN A THICKNESS AND A MACH NUMBER, THE PROGRAM CALCULATES THE DRAG-
C     DIVERGENCE MACH NUMBER BY LINEAR INTERPOLATION, AND TESTS TO SEE IF THE
C     SPECIFIED MACH NUMBER IS ABOVE OR BELOW THE DRAG DIVERGENCE MACH NUMBER.
C     IT THEN CALCULATES CDZERO ACCORDINGLY.
C
C     A. FOR SUBSONIC SECTION VELOCITIES:
C
C       THE SUBROUTINE PERFORMS A LINEAR INTERPOLATION IF THE LOCAL MACH IS
C       BELOW THE DRAG DIVERGENCE MACH NUMBER,OR USES A POLYNOMIAL CURVE FIT
C       FOR LOCAL MACH NUMBERS ABOVE THE DRAG DIVERGENCE MACH NUMBER.
C
C
C     B.  FOR SUPERSONIC SECTION VELOCITIES:
C
C        THE SUBROUTINE USES A POLYNOMIAL CURVE FIT ON THE SUPERSONIC PORTION
C        OF THE CURVE TO ARRIVE AT A VALUE FOR CDZERO.
C
C
C      ***NOTE*****
C      IF THE THICKNESS IS LESS THAN .03 OR IF CDZERO IS NEGATIVE, THEN
C      CDZERO IS SET EQUAL TO 0.0.
C
C
C
C
C
C
C
C
C
C
C                 CALCULATION OF CDLIFT
C
C
C      DATA FOR CDLIFT CALCULATION COMES FROM FIGURE 9A, P.26 IN COOPER.
C
C      FIRST:
C
C      DELTA=(CL-XCLI)
C
C      THEN IT CALCULATES XMXT, THE WEIGHTED MACH NUMBER
C
C      XMXT=XM/(.9-XTC)
C
C      THEN IT CALCULATES DELCD USING THE FORMULA AT THE TOP OF FIGURE 9A.
C
C      DELCD=(XMXT**2-XMXT-.1765)*(-.4397*DELTA**2+.1173*DELTA-.0938)
C
C      NEXT, TESTM IS CALCULATED. TESTM IS THE VALUE OF XMXT ON THE LINE
C      LABELED LIM A  WHICH CORRESPONDS TO THE VALUE OF DELCD JUST CALCULATED.
C      OBTAINED.
C
C      TESTM=(DELCD-.03)*(.9-.875)/(.03-.08)+.9
C
C      IF THE VALUE OF XMXT IS GREATER THAN TESTM, THE EQUATION ABOVE DOES
C      NOT HOLD. THEN THE VALUE OF DELCD IS ARRIVED AT BY USING A 6TH
C      DEGREE POLYNOMIAL CURVE FIT TO FIND THE SLOPE OF THE PLOT. THEN:
C
C      DELCD=SLOPE*(XMXT-1.011111)+.0911111
C
C      THEN THE SUBROUTINE TESTS IF YOU HAVE A SUPERSONIC MACH NUMBER.
C      IF SO:
C
C      DELCD= SQRT(XM**2-1)/4  AND
C      DELTA= CL
C
C      ONCE DELTA AND CL HAVE BEEN CALCULATED IN THE PROPER MANNER,
C      CDLIFT IS GIVEN BY:
C
C      CDLIFT=DELCD*DELTA**2
C
C
C
```

```
C
C
C               CALCULATION OF CDFRIC
C
C
C
C
C        THE COEFFICIENT OF DRAG DUE TO FRICTION IS A FUNCTION OF REYNOLDS
C        NUMBER AND PERCENT LAMINAR FLOW; AND IS CALCULATED USNG FIGURES
C        10A AND 10B , PP.28-9 IN COOPER.
C
C        FIGURE 10B IS A CURVE OF PERCENT LAMINAR FLOW -VS- RADIAL LOCATION.
C        FROM THIS CURVE THE SUBROUTINE FINDS THE PERCENT LAMINAR FLOW OVER
C        THE AIRFOIL (PLAM) BY A 2ND. DEGREE POLYNOMIAL CURVE FIT.
C
C        PLAM=(33.+1./3.)*XR**2+(8.+1./3.)*XR+17.0
C
C        THEN THE REYNOLDS NUMBER FOR THE AIRFOIL IS CALCULATED BY:
C
C        XRN=DEN*XM*WA*CHORD/VIS
C
C        WHEN WE HAVE REYNOLDS NUMBER AND PERCENT LAMINAR FLOW, CDFRIC IS
C        CALCULATED FROM:
C
C        CDFRIC=2.65/SQRT(XRN)+(100-PLAM)/PLAM*(.944/DLOG10(XRN)**2.65/SQRT(
C       &SQRT(XRN))
C        ***NOTE****
C        THIS IS FOUND ON P. 25 IN COOPER
C
C
C
C
C
C
C
C
C                      CALCULATION OF CDCAMB
C
C
C
C
C       CDCAMB, 'THE DRAG DUE TO CAMBER REPRESENTS THE INCREASE IN THE
C       MINIMUM BASIC DRAG COEFFICIENT OF CAMBERED NACA 16-SERIES AIRFOILS
C       OVER THAT OF THE UNCAMBERED AIRFOILS OF THE SAME SERIES'- COOPER
C
C
C       CDCAMB IS CALCULATED FROM FIGURE 11, P.30 IN COOPER. THIS IS A PLOT
C       OF CDCAMB -VS- XMXT AS FUNCTION OF CLD.
C
C       THE SUBROUTINE PERFORMS A SERIES OF LINEAR INTERPOLATIONS TO FIND
C       THE PROPER CDCAMB AT A SPECIFIED XMXT FOR A SPECIFIED CLD.
C
C
C
C
C
C                      CALCULATION OF MOMENT COEFFICIENTS
C
C
C
C       ABOUT THE QUARTER CHORD (CMQC)
C
C       DATA TABLES FOR THE MOMENT COEFFICIENTS ABOUT THE QUARTER
C       CHORD ARE SET UP FOR CLDS' OF 0.0, 0.1, 0.3, AND 0.5 AT MACH
C       NUMBERS OF 0.3, 0.45, 0.6, 0.7, AND 0.75 WITH THICKNESS RATIOS
C       OF .02, .06, .09, .12, .15, .21, AND .30.  A LAGRANGIAN INTER-
C       POLATION ROUTINE INTERPOLATES BETWEEN THE TABLES TO OBTAIN THE
C       DESIRED MOMENT COEFFICIENT. THE DATA TABLES ARE EXTRACTED FROM
C       LINDSEY, W.F., D.B. STEVENSON, AND BERNARD N. DALEY, "AERODYNA-
C       MIC CHARACTERISTICS OF 24 NACA 16-SERIES AIRFOILS AT MACH NUMBERS
C       BETWEEN 0.3 AND 0.8" NACA TN1546, FIG. 7-9, PP. 57-72.
C
C       ABOUT THE LEADING EDGE (CMLE)
C
C       THE MOMENT COEFFICIENT ABOUT THE LEADING EDGE IS TRANSFORMED
C       FROM THE QUARTER CHORD WITH THE FOLLOWING EQUATION:
C                           CMLE = CMQC-0.25*CL
C
C
```

```
C
      DIMENSION CLF(30,30),CDL(30,30),CDFR(30,30),CDC(30,30),CDF(30,30)
      DIMENSION CDZ(30,30),CM(30,30),RLD(30,30)
      DIMENSION ANGLE(3),ANG(30)
      DIMENSION RN(30)
      REAL MXMACH
      REAL M(3)
      DATA M/0.3,0.5,0.7/
      DATA ANGLE/0.0,2.0,4.0/
      DATA ALTUDE/0./
      DATA CHORD/1.000/
      DATA TC/0.15/
      DATA CLD/0.2/
      DATA ICL/1/
      DATA ICD/1/
      DATA X/.50/
      DATA NUMACH/3/
      DATA NUMALP/3/
      DATA IFORM/1/
      DATA MP/1/
      DATA L/1/
C
C
      CALL ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
      ALPHAO=-CLD/(0.1096*SQRT((1+TC)/(1-TC)))
      CALL N16COR(L,CHORD,TC,CLD,AREA)
      CALL TEST(TC,MXMACH)
      WRITE(6,10)
   10 FORMAT('1',56X,'*** LIMITATIONS ***'//)
      DO 21 K=1,NUMACH
C
   36 DO 42 J=1,NUMALP
C
      ANG(J)=ANGLE(J)-ALPHAO
C
      CALL  CLCD(M(K),ANG(J),CLF(K,J),CDF(K,J),ICL,ICD,CHORD,TC,RN(K)
     &,CLD,X,WA,VIS,DEN,CDFR(K,J),CDL(K,J),CDC(K,J),CDZ(K,J))
      RLD(K,J) = CLF(K,J)/CDF(K,J)
      IF(MP.EQ.0) GO TO 5
      HMIN=0.3
      HMAX=0.75
      TCMIN=0.02
      TCMAX=0.30
      CLFMIN=-0.3
      CLFMAX=1.0
      IF(M(K).LT.HMIN) WRITE(6,22) M(K),HMIN
   22 FORMAT(' ',9X,'MACH NO. = ',F10.6,' IS LESS THAN MACH',
     &' NO.(MIN) = ',F10.6,' FOR THE MOMENT COEFFICIENT'/)
      IF(M(K).GT.HMAX) WRITE(6,31) M(K),HMAX
   31 FORMAT(' ',9X,'MACH NO. = ',F10.6,' IS GREATER THAN MACH NO.'
     &,'(MAX) = ',F10.6,' FOR THE MOMENT COEFFICIENT'/)
      IF(TC.LT.TCMIN) WRITE(6,43) TC,TCMIN
   43 FORMAT(' ',9X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',
     &F10.6,' FOR THE MOMENT COEFFICIENT'/)
      IF(TC.GT.TCMAX) WRITE(6,50) TC,TCMAX
   50 FORMAT(' ',9X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' FOR THE MOMENT COEFFICIENT'/)
      IF(CLF(K,J).LT.CLFMIN) WRITE(6,60) CLF(K,J),CLFMIN
   60 FORMAT(' ',9X,'CL = ',F10.6,' IS LESS THAN CLMIN = ',F10.6,
     &' FOR THE MOMENT COEFFICIENT'/)
      IF(CLF(K,J).GT.CLFMAX) WRITE(6,65) CLF(K,J),CLFMAX
   65 FORMAT(' ',9X,'CL = ',F10.6,' IS GREATER THAN CLMAX = ',F10.6,
     &' FOR THE MOMENT COEFFICIENT'/)
      CM0QC=CM0FF(M(K),TC,CLF(K,J))
      CM1QC=CM1FF(M(K),TC,CLF(K,J))
      CM3QC=CM3FF(M(K),TC,CLF(K,J))
      CM5QC=CM5FF(M(K),TC,CLF(K,J))
C VARIABLE 'CM.NO.QC':  'CM'   = MOMENT COEFFICIENT
C                       '.NO.' = DESIGN LIFT COEFFICIENT * 10
C                       'QC'   = QUARTER CHORD
      CLDMIN=0.0
      CLDMAX=0.5
      IF(CLD.LT.CLDMIN) WRITE(6,55) CLD,CLDMIN
   55 FORMAT(' ',9X,'CLD = ',F10.6,' IS LESS THAN CLDMIN = ',F10.6,
```

```
     &' FOR THE MOMENT COEFFICIENT'/)
      IF(CLD.LE.0.1) GO TO 4
      IF(CLD.LE.0.3) GO TO 1
      IF(CLD.LE.0.5) GO TO 2
      WRITE(6,70) CLD,CLDMAX
   70 FORMAT(' ',9X,'CLD = ',F10.6,' IS GREATER THAN CLDMAX = ',F10.6,
     &' FOR THE MOMENT COEFFICIENT'/)
      GO TO 2
    4 Y1=CM1QC-CM0QC
      X1=0.1
      X2=CLD
      Y2=Y1*X2/X1
      GO TO 3
    1 Y1=CM3QC-CM1QC
      X1=0.2
      X2=CLD-0.1
      Y2=Y1*X2/X1
      GO TO 3
    2 Y1=CM5QC-CM3QC
      X1=0.2
      X2=CLD-0.3
      Y2=Y1*X2/X1
    3 CM(K,J)=Y2
      IF(MP.EQ.1) CM(K,J)=CM(K,J)-0.25*CLF(K,J)
    5 IF(MP.EQ.0) CM(K,J)=0.0
C
      IF(TC.GT.0.1) GO TO 281
      IF(M(K).LT.0.5) GO TO 281
      IF(M(K).GE.1.0) ALTEST=999.99
      CALL AOAT(M(K),ALTEST,K)
      IF(ANGLE(J).GT.ALTEST) WRITE(6,20) ANGLE(J),ALTEST
   20 FORMAT(' ',9X,'ANGLE = ',F10.6,' IS GREATER THAN MAX.',
     &'ANGLE = ',F10.6/)
C
C
  281 IF(M(K).LT.MXMACH) GO TO 42
      IF(M(K).GE.1.0) GO TO 42
      WRITE(6,30) M(K),MXMACH
   30 FORMAT(' ',9X,'MACH NO. = ',F10.6,' IS GREATER THAN MACH NO.',
     &'(MAX) = ',F10.6,' FOR SUBSONIC SPEED'/)
   42 CONTINUE
C
   21 CONTINUE
C
C
      IF(IFORM.EQ.1) GO TO 53
C
      DO 87 KK=1,NUMACH
C
C
      DO 88 LL=1,NUMALP
C
      WRITE(6,254)
  254 FORMAT('1',39X,'*',1X,'NACA 16,6 SERIES AIRFOIL DATA BANK',
     &1X,'*'////)
      WRITE(6,900) CLD,ALPHAO,TC,M(KK),ANGLE(LL),ALTUDE
  900 FORMAT(30X,'INPUT PARAMETERS'/25X,32('*')
     &/25X,'*',30X,'*'/25X,'*',30X,'*'/25X,'*',5X
     &,'CLD=',F10.7,11X,'*'/25X,'*',30X,'*'/25X,'*',30X
     &,'*'/25X,'*',5X,'ALPHALO=',F10.7,9X,'*'/
     &25X,'*',30X,'*'/25X,'*',30X
     &,'*'/25X,'*',5X,'T/C=',F10.7,11X,'*'/25X,'*',
     &30X,'*'/25X,'*',30X,'*'/25X,'*',5X,'MACH=',
     &F10.7,10X,'*'/25X,'*',30X,'*'/25X,'*',30X,'*'
     &/25X,'*',5X,'ALPHA=',F10.7,9X,'*'/25X,'*',
     &30X,'*'/25X,'*',30X,'*'/25X,'*',5X,'ALTITUDE=',
     &F10.3,6X,'*'/25X,'*',30X,'*'/25X,'*',30X,'*'/25X,32('*'))
C
C
      WRITE(6,99) CLF(KK,LL)
   99 FORMAT(20X,'LIFT COEFFICIENT=',F10.6///)
      WRITE(6,100) CDL(KK,LL)
  100 FORMAT(20X,'INCREMENT IN DRAG COEFFICIENT DUE TO LIFT=',F10.6)
      WRITE(6,101) CDFR(KK,LL)
```

```
 101  FORMAT(///20X,'INCREMENT IN DRAG COEFFICIENT DUE TO FRICTION=',
     &F10.6)
      WRITE(6,102) CDC(KK,LL)
 102  FORMAT(///20X,'INCREMENT IN DRAG COEFFICINT DUE TO CAMBER=',F10.6)
      WRITE(6,103) CDZ(KK,LL)
  103 FORMAT(///20X,'BASIC DRAG COEFFICIENT=',F10.6)
      WRITE(6,104) CDF(KK,LL)
  104 FORMAT(///20X,'TOTAL DRAG COEFFICIENT=',F10.6)
C
   88 CONTINUE
C
C
   87 CONTINUE
C
  53  CONTINUE
C
      J=0
      IF(NUMACH.EQ.1) GO TO 44
      NUMT=NUMACH
      DO 40 JJ=1,NUMACH
      WRITE(6,852)
  852 FORMAT('1',11X,'* NACA 16,6 SERIES AIRFOIL DATA BANK *',22X,
     &'* NACA 16,6 SERIES AIRFOIL DATA BANK *'////)
      WRITE(6,515) ALTUDE,ALTUDE
  515 FORMAT(T20,'ALTITUDE = ',F10.4,1X,'FEET',T83,'ALTITUDE = ',
     &F10.4,1X,'FEET'/)
      WRITE(6,117) CHORD,CHORD
  117 FORMAT(T23,'CHORD =    ',F10.6,1X,'FEET',T86,'CHORD =    ',
     &F10.6,1X,'FEET'/)
      WRITE(6,701) TC,TC,CLD,CLD
  701 FORMAT(T20,'(T/C)MAX =    ',F10.6,T82,'(T/C)MAX =    ',F10.6,
     &//T25,'CLD =    ',F10.6,T87,'CLD =    ',F10.6/)
      WRITE(6,283) ALPHAO,ALPHAO
  283 FORMAT(T21,'ALPHALO =    ',F10.6,1X,'DEG.',T84,'ALPHALO =    ',
     &F10.6,1X,'DEG.'/)
      WRITE(6,700) M(J+1),M(J+2)
  700 FORMAT(T20,'MACH NO. =    ',F10.6,T83,'MACH NO. =    ',F10.6/)
      WRITE(6,729)RN(J+1),RN(J+2)
  729 FORMAT(T16,'REYNOLDS NO. =    ',E14.6,T79,'REYNOLDS NO. =    ',
     &E14.6,//)
C
      IF(MP.EQ.2) GO TO 82
      WRITE(6,555)
  555 FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(LED)'
     &,T73,'ALPHA',T86,'CL',T98,'CD',T108,'CL/CD',T120,'CM(LED)'/)
      GO TO 83
 82   WRITE(6,556)
 556  FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(1/4)'
     &,T73,'ALPHA',T86,'CL',T98,'CD',T108,'CL/CD',T120,'CM(1/4)')
C
 83   CONTINUE
      DO 41 N=1,NUMALP
C
      WRITE(6,600) ANGLE(N),CLF(J+1,N),CDF(J+1,N),RLD(J+1,N),CM(J+1,N)
     &,ANGLE(N),CLF(J+2,N),CDF(J+2,N),RLD(J+2,N),CM(J+2,N)
 600  FORMAT(2(5X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6))
C
  41  CONTINUE
C
      J=JJ*2
      NUMT=NUMT-2
      IF(NUMT.EQ.0) GO TO 33
      IF(NUMT.EQ.1) GO TO 44
C
   40 CONTINUE
C
C
C
  44  WRITE(6,589)
  589 FORMAT('1',39X,'*',1X,'NACA 16,6 SERIES AIRFOIL DATA BANK',
     &1X,'*'////)
      WRITE(6,214) ALTUDE
  214 FORMAT(T11,'ALTITUDE = ',F10.4,1X,'FEET'/)
      WRITE(6,339) CHORD
```

```
  339 FORMAT(T14,'CHORD =',F10.6,1X,'FEET')
      WRITE(6,152) TC
 152  FORMAT(/T11,'(T/C)MAX = ',F10.6/)
      WRITE(6,151) CLD
  151 FORMAT(T16,'CLD = ',F10.6/)
      WRITE(6,888) ALPHAO
  888 FORMAT(T12,'ALPHALO = ',F10.6/)
      WRITE(6,150) M(NUMACH)
  150 FORMAT(T11,'MACH NO. = ',F10.6/)
      WRITE(6,912)RN(NUMACH)
  912 FORMAT(/T7,'REYNOLDS NO. = ',F10.6//)
C
      IF(MP.EQ.2) GO TO 84
      WRITE(6,666)
  666 FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(LED)'/)
      GO TO 85
 84   WRITE(6,665)
 665  FORMAT(T10,'ALPHA',T23,'CL',T35,'CD',T45,'CL/CD',T57,'CM(1/4)'/)
C
 85   CONTINUE
      DO 66 N=1,NUMALP
      WRITE(6,250) ANGLE(N),CLF(NUMACH,N),CDF(NUMACH,N),RLD(NUMACH,
     &N),CM(NUMACH,N)
  250 FORMAT(5X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6,2X,F10.6)
  66  CONTINUE
C
      GO TO 33
C
   33 WRITE(6,999)
  999 FORMAT('1')
      STOP
      END
C
C
C
      SUBROUTINE CLCD(XM,ALPHA,CL,CD,ICL,ICD,CHORD,XTC,XRN,XCLI,XR
     &,WA,VIS,DEN,CDFRIC,CDLIFT,CDCAMB,CDZERO)
C
C
      DIMENSION CDD(6),CLIT(6),A(6),B(6),C(6),D(6),E(6),F(6),G(6)
      DIMENSION TB(11),DMACH(11),CD0(11),CD01(6),TB1(6),AA(6),BB(6)
      DIMENSION CC(6),DD(6),EE(6),FF(6)
      DOUBLE PRECISION AA,BB,CC,DD,EE,FF
      DATA A/1.325276,.1024011,.2890272,.5288957,1.177606,2.125449/
      DATA B/-5.133061,-.0976595,-.2461832,-.0205697,-.2953677,.1974199/
      DATA C/8.412967,-.2752136,-.8075892,-2.787452,-5.423342,-11.9608/
      DATA D/-7.325109,.5574539,1.520081,4.335364,8.694619,18.21422/
      DATA E/3.522405,-.3924382,-1.018046,-2.761126,-5.583289,-11.50479/
      DATA F/-.8777567,.1226128,.3042805,.8093843,1.64263,3.357388/
      DATA G/.087806,-.0140459,-.0334875,-.0889465,-.1814412,-.3697504/
      DATA TB/.031,.0625,.1,.1375,.175,.2125,.25,.2875,.325,.3625,.4/
      DATA CD0/0.0,.00025,.00065,.0013,.0022,.0033,.00465,.0061,
     &.0078,.01,.013/
      DATA DMACH/.9,.84,.79,.75,.72,.7,.68,.665,.65,.6375,.62/
      DATA AA/-5.834527753,-1.45916514,8.3327673,2.6038473,-.10428842,.2
     &08297374/
      DATA BB/37.09086074,9.58857686,-51.4547602,-16.2479854,.78201755,-
     &1.2497732/
      DATA CC/-94.01887327,-25.1902339,126.241026,40.198068,-2.2988001,2
     &.94734747/
      DATA DD/118.8401952,33.12056567,-153.736709,-49.206188,3.3320883,-
     &3.39928973/
      DATA EE/-74.98024889,-21.858250,92.8384573,29.7250413,-2.3960093,
     &1.903809351/
      DATA FF/18.94459392,5.83350647,-22.1932814,-7.0552833,.689991999,-
     &.408891283/
      PLAM=(33.+1./3.)*XR**2+(8.+1./3.)*XR+17.0
      TCMIN=0.02
      TCMAX=0.30
      IF(XTC.LT.TCMIN) WRITE(6,21) XTC,TCMIN
  21  FORMAT(' ',9X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',F10.6,
     &' FOR THE LIFT CURVE SLOPE'/)
      IF(XTC.GT.TCMAX) WRITE(6,30) XTC,TCMAX
  30  FORMAT(' ',9X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
```

```
     &F10.6,' FOR THE LIFT CURVE SLOPE'/)
      IF(XM.LT.1.0) GO TO 1
      DCLDA=.0698/SQRT(XM**2-1)
      GO TO 2
    1 IF(ICL.EQ.0) DCLDA=.1096*(1-XTC)/SQRT(1-XTC**2)
      IF(ICL.EQ.0) GO TO 2
      DCLDA=.1096/SQRT(1-(XM)**2)
      IF((XM+XTC).GE.1.0) GO TO 2
      DCLDA=.1096*(1.-XTC)/SQRT(1-(XM+XTC)**2)
    2 CL=ALPHA*DCLDA
      XRN=DEN*XM*WA*CHORD/VIS
C     XRN=3000000.0   IS THIS SUPPOSE TO BE HERE? --- WINTER
C     IF(ICD.EQ.0) RETURN
      DELTA=CL-XCLI
      XMXT=XM/(.9-XTC)
      DELCD=(XMXT**2-XMXT-.1765)*(-.4397*DELTA**2+.1173*DELTA-.0938)
      TESTM=(DELCD-.03)*(.9-.875)/(.03-.08)+.9
      IF(XMXT.GT.TESTM) GO TO 3
      GO TO 4
    3 SLOPE=-117.218415*DELTA**6+321.890357*DELTA**5-332.087766*DELTA**4
     &+151.8614153*DELTA**3-24.597998*DELTA**2-2.6451615*DELTA+1.48
      DELCD=SLOPE*(XMXT-1.011111)+.0911111
    4 IF(XM.GE.1.0) DELCD=SQRT(XM**2-1)/4.
      IF(XM.GE.1.0) DELTA=CL
      CLDMX=0.8
      IF(DELTA.GT.CLDMX) WRITE(6,40) DELTA,CLDMX
   40 FORMAT(' ',9X,'(CL-CLD) = ',F10.6,' IS GREATER THAN (CL-CLD)',
     &'(MAX.) = ',F10.6,' FOR DRAG DUE TO LIFT'/)
      CDLIFT=DELCD*DELTA**2
      IF(CDLIFT.LT.0.0) CDLIFT=0.0
      CDFRIC=2.65/SQRT(XRN)+(100-PLAM)/100.*(.944/(ALOG10(XRN)**2.6)-2.6
     &5/SQRT(XRN))
      IF(XMXT.GT.1.0) GO TO 8
      DO 5 I=1,6
      CDD(I)=A(I)*XMXT**6+B(I)*XMXT**5+C(I)*XMXT**4+D(I)*XMXT**3+E(I)*XM
     &XT**2+F(I)*XMXT+G(I)
    5 CLIT(I)=FLOAT(I)/10.+.1
      SUM=0.0
      DO 7 IX=1,6
      S=CDD(IX)
      DO 6 JX=1,6
      IF(JX.EQ.IX) GO TO 6
      S=S*(XCLI-CLIT(JX))/(CLIT(IX)-CLIT(JX))
    6 CONTINUE
      SUM=SUM+S
    7 CONTINUE
      CLDMIN=0.0
      CLDMAX=0.7
      IF(XCLI.LT.CLDMIN) WRITE(6,50) XCLI,CLDMIN
   50 FORMAT(' ',9X,'CLD = ',F10.6,' IS LESS THAN CLDMIN = ',F10.6,
     &' FOR DRAG DUE TO CAMBER'/)
      IF(XCLI.GT.CLDMAX) WRITE(6,60) XCLI,CLDMAX
   60 FORMAT(' ',9X,'CLD = ',F10.6,' IS GREATER THAN CLDMAX = ',F10.6,
     &' FOR DRAG DUE TO CAMBER'/)
      CDCAMB=SUM
      IF(CDCAMB.GT.0.0) GO TO 9
    8 CDCAMB=0.0
    9 IF(XM.GE..95) GO TO 14
      IF(XTC.LE..03) GO TO 19
      SUM=0.0
      DO 11 IX=1,11
      S=CDO(IX)
      DO 10 JX=1,11
      IF(JX.EQ.IX) GO TO 10
      S=S*(XTC-TB(JX))/(TB(IX)-TB(JX))
   10 CONTINUE
      SUM=SUM+S
   11 CONTINUE
      CDZERO=SUM
      SUM=0.0
      DO 13 IX=1,11
      S=DMACH(IX)
      DO 12 JX=1,11
      IF(JX.EQ.IX) GO TO 12
```

```
      S=S*(XTC-TB(JX))/(TB(IX)-TB(JX))
 12 CONTINUE
      SUM=SUM+S
 13 CONTINUE
      DIVMAC=SUM
      IF(XM.LE.DIVMAC) GO TO 18
      XCHANG=.7225+(XM-DIVMAC)
      YCHANG=CDZERO-.0023845
      CDZERO=-37732.79544*XCHANG**5+143059.1078*XCHANG**4-216835.3262*XC
     &HANG**3+164241.3211*XCHANG**2-62170.09813*XCHANG+9408.610638+YCHAN
     &G
      GO TO 18
 14 DO 15 I=1,6
      CD01(I)=AA(I)*XM**5+BB(I)*XM**4+CC(I)*XM**3+DD(I)*XM**2+EE(I)*XM+F
     &F(I)
 15 TB1(I)=FLOAT(I)/100.
      SUM=0.0
      DO 17 IX=1,6
      S=CD01(IX)
      DO 16 JX=1,6
      IF(JX.EQ.IX) GO TO 16
      S=S*(XTC-TB1(JX))/(TB1(IX)-TB1(JX))
 16 CONTINUE
      SUM=SUM+S
 17 CONTINUE
      CDZERO=SUM
 18 IF(CDZERO.LT.0.0) CDZERO=0.0
      GO TO 20
 19 CDZERO=0.0
      TCMIN=0.02
      TCMAX=0.40
      IF(XTC.LT.TCMIN) WRITE(6,70) XTC,TCMIN
70  FORMAT(' ',9X,'T/C = ',F10.6,' IS LESS THAN (T/C)MIN = ',
     &F10.6,' FOR THE BASIC DRAG'/)
      IF(XTC.GT.TCMAX) WRITE(6,80) XTC,TCMAX
80  FORMAT(' ',9X,'T/C = ',F10.6,' IS GREATER THAN (T/C)MAX = ',
     &F10.6,' FOR THE BASIC DRAG'/)
 20 CD=CDLIFT+CDFRIC+CDCAMB+CDZERO
      IF(ICL.EQ.0) CD=CDFRIC
      XRN=XRN/1000000.
C
C
C
C
      RETURN
      END
C
C
C *********************************************************************
C
C     DATA FOR MOMENT COEFFICIENT ABOUT THE QUARTER CHORD
C
C *********************************************************************
C
C
      FUNCTION CMOFF(M,TC,CLF)
      DIMENSION A(5),X(3),Y(3)
      REAL M
C DATA A = MACH NO.
      DATA A/0.3,0.45,0.6,0.7,0.75/
      N=2
      IS=1
      IL=IS+N-1
      IF(M.LE.A(IL)) GO TO 2
      IL=2
      IS=IL-N+1
      IF(M.GE.A(IS)) GO TO 2
      IS=1
      IL=IS+N-1
  3  IF((M-A(IS))*(M-A(IL)).LE.0.0) GO TO 2
      IS=IL
      IL=IS+N-1
      GO TO 3
  2  DO 4 I=IS,IL
```

```
      J=I-IS+1
      X(J)=A(I)
      GO TO (30,45,60,70,75),I
C DATA 'CM.NO.':  'CM'  = MOMENT COEFFICIENT ABOUT THE QUARTER CHORD
C                 '.NO.'= CLD*10 AND MACH NUMBER*100
  30  Y(J)=CM030(M,TC,CLF)
      GO TO 4
  45  Y(J)=CM045(M,TC,CLF)
      GO TO 4
  60  Y(J)=CM060(M,TC,CLF)
      GO TO 4
  70  Y(J)=CM070(M,TC,CLF)
      GO TO 4
  75  Y(J)=CM075(M,TC,CLF)
   4  CONTINUE
      CMOFF=YLAGN(X,Y,N,M)
      RETURN
      END
C
C
C
      FUNCTION CM030(M,TC,CLF)
      DIMENSION T(7),CL2(11),CM2(11),CL6(11),CM6(11),CL9(11),CM9(11),
     &CL12(11),CM12(11),CL15(10),CM15(10),CL21(9),CM21(9),CL30(5),
     &CM30(5)
      REAL M
C DATA IS FROM NACA TN1546, PP.57-72, FIG. 7-9
C DATA T = TC = THICKNESS RATIO
C DATA 'CL.NO.': 'CL'=LIFT COEFFICIENT, '.NO.'=THICKNESS RATIO*100
C DATA 'CM.NO.': 'CM'=MOMENT COEFFICIENT ABOUT THE QUARTER CHORD,
C                '.NO.'=THICKNESS RATIO*100
      DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM2/-.0135,-.00825,-.01775,-.015,-.007,-.0055,0.01525,
     002,0.0235,-.016,-.04925/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM6/-.0135,-.01575,-.011,-.00375,-.0025,-.007,-.00075,
     0012,0.011,-.0055,0.02525/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM9/-.0135,-.005,-.001,0.003,0.005,0.00925,0.0035,0.00975,
     0006,0.0085,0.057/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM12/0.003,0.00925,0.009,0.009,0.017,0.046,0.0315,0.0275,
     00185,0.0365,0.063/
      DATA CL15/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM15/0.001,0.004,0.0105,0.039,0.09,0.097,0.061,0.061,
     007,0.053/
      DATA CL21/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM21/0.005,0.01125,0.015,0.019,0.094,0.064,0.123,0.204,
     0109/
      DATA CL30/-0.1,0.0,0.1,0.2,0.3/
      DATA CM30/-.022,0.013,0.0305,0.0565,0.167/
      CM030=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,11,11,11,11,10,9,5)
      RETURN
      END
C
C
C
      FUNCTION CM045(M,TC,CLF)
      DIMENSION T(7),CL2(11),CM2(11),CL6(11),CM6(11),CL9(11),CM9(11),
     &CL12(11),CM12(11),CL15(10),CM15(10),CL21(9),CM21(9),CL30(5),
     &CM30(5)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM2/-.0035,0.012,0.011,-.005,-.006,-.01,-.008,0.0085,0.019,
     &-.05,-.03675/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM6/-.01175,-.003,0.003,0.0275,0.0,0.002,0.00625,0.0045,
     0012,-.0225,0.013/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM9/-.01475,-.012,0.0,0.00625,0.012,0.024,0.02475,0.02,
     00175,0.01225,0.038/
```

```
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM12/-.011,0.012,-.002,0.005,0.028,0.074,0.097,0.053,0.047,
     0054,0.032/
      DATA CL15/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM15/0.011,0.006,0.013,0.062,0.112,0.107,0.084,0.0845,
     0084,0.0785/
      DATA CL21/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM21/0.0005,0.0075,0.02,0.08225,0.135,0.085,0.236,0.191,
     0158/
      DATA CL30/-0.1,0.0,0.1,0.2,0.3/
      DATA CM30/-.01425,0.00925,0.0405,0.179,0.216/
      CM045=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,11,11,11,11,10,9,5)
      RETURN
      END
C
C
C
      FUNCTION CM060(M,TC,CLF)
      DIMENSION T(7),CL2(11),CM2(11),CL6(10),CM6(10),CL9(11),CM9(11),
     &CL12(10),CM12(10),CL15(11),CM15(11),CL21(10),CM21(10),CL30(4),
     &CM30(4)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM2/0.034,0.063,0.004,0.023,0.01,0.004,-.023,-.017,
     000875,-.0415,-.049/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM6/0.002,-.002,0.002,0.004,0.008,0.009,0.01,0.01225,0.014,
     0014/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM9/-.01375,0.004,0.003,0.006,0.015,0.03075,0.046,0.046,
     0035,0.053,0.0395/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM12/0.001,0.0305,0.02,0.01475,0.0405,0.088,0.108,0.1005,
     0082,0.1/
      DATA CL15/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM15/0.032,0.031,0.0187,0.013,0.0525,0.13625,0.16875,
     01275,0.11625,0.1225,0.0985/
      DATA CL21/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM21/-.013,-.009,0.0725,0.102,0.06275,0.0975,0.284,0.273,
     0239,0.196/
      DATA CL30/-0.1,0.0,0.1,0.2/
      DATA CM30/-.033,-.028,0.142,0.213/
      CM060=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,11,10,11,10,11,10,4)
      RETURN
      END
C
C
C
      FUNCTION CM070(M,TC,CLF)
      DIMENSION T(5),CL2(10),CM2(10),CL6(10),CM6(10),CL9(10),CM9(10),
     &CL12(9),CM12(9),CL15(8),CM15(8)
      DIMENSION CL21(1),CL30(1),CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM2/0.0145,-.022,-.008,0.025,0.038,0.024,0.024,0.004,
     0002,-.026/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM6/-.015,-.008,-.00225,0.0125,0.022,0.024,0.0255,0.0255,
     0023,0.019/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM9/-.02,0.004,0.002,0.009,0.012,0.023,0.059,0.0165,
     003375,0.0485/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM12/0.009,0.026,0.031,0.031,0.021,0.0465,0.031,0.046,0.073/
      DATA CL15/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM15/0.083,0.02375,0.0185,0.037,0.108,0.002,-.011,-.0275/
      CM070=CMTHKF(M,TC,CLF,T,5,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,10,10,10,9,8,0,0)
      RETURN
      END
```

```
C
C
C
      FUNCTION CM075(M,TC,CLF)
      DIMENSION T(3),CL2(8),CM2(8),CL6(9),CM6(9),CL9(8),CM9(8)
      DIMENSION CL12(1),CL15(1),CL21(1),CL30(1),CM12(1),CM15(1),
     &CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6/
      DATA CM2/0.008,0.1675,0.0425,-.01,0.0125,0.02,0.7,0.69/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM6/-.01125,-.0015,0.00375,0.014,0.027,0.0305,0.007,0.012,
     0014/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6/
      DATA CM9/-.021,0.0185,0.0495,0.0565,0.056,0.0615,0.052,0.052/
      CM075=CMTHKF(M,TC,CLF,T,3,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,8,9,8,0,0,0,0)
      RETURN
      END
C
C
C
      FUNCTION CM1FF(M,TC,CLF)
      DIMENSION A(5),X(3),Y(3)
      REAL M
      DATA A/0.3,0.45,0.6,0.7,0.75/
      N=2
      IS=1
      IL=IS+N-1
      IF(M.LE.A(IL)) GO TO 2
      IL=2
      IS=IL-N+1
      IF(M.GE.A(IS)) GO TO 2
      IS=1
      IL=IS+N-1
    3 IF((M-A(IS))*(M-A(IL)).LE.0.0) GO TO 2
      IS=IL
      IL=IS+N-1
      GO TO 3
    2 DO 4 I=IS,IL
      J=I-IS+1
      X(J)=A(I)
      GO TO (30,45,60,70,75),I
   30 Y(J)=CM130(M,TC,CLF)
      GO TO 4
   45 Y(J)=CM145(M,TC,CLF)
      GO TO 4
   60 Y(J)=CM160(M,TC,CLF)
      GO TO 4
   70 Y(J)=CM170(M,TC,CLF)
      GO TO 4
   75 Y(J)=CM175(M,TC,CLF)
    4 CONTINUE
      CM1FF=YLAGN(X,Y,N,M)
      RETURN
      END
C
C
C
      FUNCTION CM130(M,TC,CLF)
      DIMENSION T(7),CL2(10),CM2(10),CL6(13),CM6(13),CL9(13),CM9(13),
     &CL12(10),CM12(10),CL15(15),CM15(15),CL21(5),CM21(5),CL30(11),
     &CM30(11)
      REAL M
      DATA T/.02,.06,.09,.12,.15,.21,.30/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM2/-.03,-.034,-.0406,-.037,-.032,-.0275,-.02,-.0075,
     &-.005,-.025/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.7,0.75,
     08/
      DATA CM6/-.03,-.0275,-.025,-.0225,-.02,-.02,-.0175,-.015,-.0075,
     &-.005,-.005,-.008,-.0125/
      DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.725,0.75,
```

```
0775,0.8/
 DATA CM9/-.03,-.0225,-.0175,-.015,-.0125,-.01,-.01,-.0075,-.005,
&-.005,-.001,0.0,0.0/
 DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM12/-.023,-.0175,-.0144,-.0112,-.005,0.0115,0.012,
0012,0.01,0.021/
 DATA CL15/-0.1,0.0,0.1,0.2,0.225,0.25,0.275,0.3,0.35,0.4,0.425,
05,0.6,0.7,0.8/
 DATA CM15/-.0175,-.0125,-.01,-.0075,-.005,-.0025,0.0,0.0075,
00225,0.04,0.0475,0.0475,0.0475,0.045,0.045/
 DATA CL21/-0.1,0.0,0.1,0.2,0.3/
 DATA CM21/-.0175,-.0025,0.003,0.0085,0.056/
 DATA CL30/-0.1,-0.05,0.0,0.1,0.15,0.2,0.225,0.25,0.2625,0.275,0.3/
 DATA CM30/-.0175,0.0,0.0125,0.0275,0.035,0.05,0.0625,0.0875,
01175,0.1325,0.14/
 CM130=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,10,13,13,10,15,5,11)
 RETURN
 END
C
C
C
 FUNCTION CM145(M,TC,CLF)
 DIMENSION T(7),CL2(10),CM2(10),CL6(15),CM6(15),CL9(10),CM9(10),
&CL12(10),CM12(10),CL15(16),CM15(16),CL21(5),CM21(5),CL30(10),
&CM30(10)
 REAL M
 DATA T/.02,.06,.09,.12,.15,.21,.30/
 DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM2/-.0275,-.0175,-.0225,-.036,-.035,-.0325,-.03,-.0225,
&-.00625,-.05/
 DATA CL6/-0.1,-0.05,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.625,0.675,0.7,
0725,0.75,0.8/
 DATA CM6/-.033,-.0285,-.025,-.0225,-.021,-.02,-.0175,-.015,-.013,
&-.01,-.006,-.005,-.0075,-.01,-.025/
 DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM9/-.035,-.03,-.0225,-.015,-.01,-.0025,0.0,0.001,0.001,0.0/
 DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM12/-.035,-.025,-.02375,-.0165,0.00125,0.029,0.04675,
00295,0.0265,0.0295/
 DATA CL15/-0.1,0.0,0.1,0.2,0.225,0.25,0.275,0.3,0.325,0.35,0.4,
045,0.5,0.6,0.7,0.8/
 DATA CM15/-.0225,-.02,-.0125,-.005,-.005,0.0,0.005,0.0175,0.0325,
004,0.0525,0.0575,0.06,0.0625,0.0625,0.0625/
 DATA CL21/-0.1,0.0,0.1,0.2,0.3/
 DATA CM21/-.0145,-.005,0.007,0.0475,0.08125/
 DATA CL30/-0.1,0.0,0.1,0.15,0.1625,0.175,0.18,0.185,0.2,0.3/
 DATA CM30/-.01,0.0125,0.0375,0.0625,0.0675,0.085,0.1,0.14,
01525,0.1825/
 CM145=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,10,15,10,10,16,5,10)
 RETURN
 END
C
C
C
 FUNCTION CM160(M,TC,CLF)
 DIMENSION T(7),CL2(10),CM2(10),CL6(10),CM6(10),CL9(10),CM9(10),
&CL12(10),CM12(10),CL15(15),CM15(15),CL21(4),CM21(4),CL30(14),
&CM30(14)
 REAL M
 DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
 DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM2/-.005,-.007,-.025,-.025,-.025,-.0285,-.04,-.035,
&-.0235,-.0535/
 DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM6/-.03,-0.275,-.025,-.0225,-.02,-.0175,-.015,-.01,
&-.0075,-.005/
 DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.65,0.7/
 DATA CM9/-.039,-.03,-.025,-.02,-.0125,-.0025,0.009,0.015,
0015,0.0125/
 DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
 DATA CM12/-.035,-.025,-.02375,-.0165,0.00125,0.029,0.04675,
0055,0.05275,0.068/
```

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      DATA CL15/-0.1,0.0,0.1,0.2,0.25,0.27,0.3,0.335,0.365,0.4,0.45,
     05,0.6,0.7,0.8/
      DATA CM15/-.029,-.02,-.015,-.0075,-.0025,0.0,0.015,0.0375,0.05,
     00625,0.0725,0.08,0.09,0.0925,0.0925/
      DATA CL21/-0.1,0.0,0.1,0.2/
      DATA CM21/-.023,-.01575,-.0335,-.058/
      DATA CL30/-0.1,0.0,0.03,0.03,0.04,0.05,0.07,0.08,0.09,0.1,
     0115,0.125,0.15,0.2/
      DATA CM30/-.015,-.01,-.009,0.04,0.0575,0.0675,0.075,0.08,0.1,
     013,0.1625,0.1725,0.1825,0.19/
      CM160=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,10,10,10,10,15,4,14)
      RETURN
      END
C
C
C
      FUNCTION CM170(M,TC,CLF)
      DIMENSION T(5),CL2(7),CM2(7),CL6(9),CM6(9),CL9(11),CM9(11),
     &CL12(6),CM12(6),CL15(10),CM15(10)
      DIMENSION CL21(1),CL30(1),CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5/
      DATA CM2/-.016,-.037,-.0325,-.02625,-.01875,-.01875,-.01875/
      DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM6/-.04,-.035,-.031,-.024,-.018,-.016,-.012,-.012,-.012/
      DATA CL9/-0.1,-0.05,0.0,0.1,0.2,0.3,0.36,0.4,0.44,0.472,0.5/
      DATA CM9/-.048,-.04,-.034,-.028,-.02,-.016,-.014,-.01,-.006,
     00,0.008/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4/
      DATA CM12/-.039,-.028,-.02075,-.0125,-.0085,0.0055/
      DATA CL15/-0.1,0.0,0.1,0.2,0.26,0.3,0.325,0.35,0.375,0.4/
      DATA CM15/-.03,-.02,-.012,-.002,0.0,0.008,0.012,0.018,0.03,
     0046/
      CM170=CMTHKF(M,TC,CLF,T,5,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,7,9,11,6,10,0,0)
      RETURN
      END
C
C
C
      FUNCTION CM175(M,TC,CLF)
      DIMENSION T(3),CL2(6),CM2(6),CL6(7),CM6(7),CL9(9),CM9(9)
      DIMENSION CL12(1),CL15(1),CL21(1),CL30(1),CM12(1),CM15(1),
     &CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4/
      DATA CM2/-.0373,-.0383,-.0373,-.0289,-.0175,-.0061/
      DATA CL6/-0.2,-0.1,0.0,0.1,0.2,0.3,0.4/
      DATA CM6/-.05,-.044,-.037,-.032,-.026,-.02,-.014/
      DATA CL9/-0.1,0.0,0.05,0.1,0.2,0.3,0.4,0.5,0.6/
      DATA CM9/-.049,-.036,-.032,-.028,-.024,-.022,-.02,-.02,-.021/
      CM175=CMTHKF(M,TC,CLF,T,3,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,6,7,9,0,0,0,0)
      RETURN
      END
C
C
C
      FUNCTION CM3FF(M,TC,CLF)
      DIMENSION A(5),X(3),Y(3)
      REAL M
      DATA A/0.3,0.45,0.6,0.7,0.75/
      N=2
      IS=1
      IL=IS+N-1
      IF(M.LE.A(IL)) GO TO 2
      IL=2
      IS=IL-N+1
      IF(M.GE.A(IS)) GO TO 2
      IS=1
      IL=IS+N-1
```

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  3  IF((M-A(IS))*(M-A(IL)).LE.0.0) GO TO 2
     IS=IL
     IL=IS+N-1
     GO TO 3
  2  DO 4 I=IS,IL
     J=I-IS+1
     X(J)=A(I)
     GO TO (30,45,60,70,75),I
 30  Y(J)=CM330(M,TC,CLF)
     GO TO 4
 45  Y(J)=CM345(M,TC,CLF)
     GO TO 4
 60  Y(J)=CM360(M,TC,CLF)
     GO TO 4
 70  Y(J)=CM370(M,TC,CLF)
     GO TO 4
 75  Y(J)=CM375(M,TC,CLF)
  4  CONTINUE
     CM3FF=YLAGN(X,Y,N,M)
     RETURN
     END
C
C
C
     FUNCTION CM330(M,TC,CLF)
     DIMENSION T(6),CL2(11),CM2(11),CL6(15),CM6(15),CL9(13),CM9(13),
    &CL12(15),CM12(15),CL15(19),CM15(19),CL21(16),CM21(16)
     DIMENSION CL30(1),CM30(1)
     REAL M
     DATA T/0.02,0.06,0.09,0.12,0.15,0.21/
     DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
     DATA CM2/-.0625,-.08065,-.082,-.0785,-.07675,-.07125,-.0785,
    &-.05875,-.05875,-.0445,-.0625/
     DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.45,0.5,0.55,0.6,0.65,0.7,
    075,0.8,0.9/
     DATA CM6/-.0625,-.06,-.06,-.06,-.0575,-.055,-.0575,-.0575,-.0525,
    &-.05,-.045,-.04,-.035,-.0325,-.03/
     DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.7,0.8,0.9/
     DATA CM9/-.0625,-.0575,-.055,-.0525,-.05,-.05,-.0425,-.0425,
    &-.0425,-.04,-.03,-.0225,-.0125/
     DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.425,0.45,0.5,0.55,0.6,0.7,
    075,0.8,0.9/
     DATA CM12/-.075,-.0675,-.06,-.0525,-.05,-.0475,-.0475,-.045,
    &-.0325,-.0275,-.025,-.0175,-.015,-.01,0.0/
     DATA CL15/0.0,0.05,0.1,0.2,0.3,0.4,0.45,0.5,0.517,0.533,0.55,
    0567,0.583,0.6,0.7,0.75,0.8,0.85,0.9/
     DATA CM15/-.05,-.05,-.0475,-.045,-.0425,-.035,-.0325,-.025,
    &-.02,-.01,0.005,0.0075,0.01,0.01,0.0075,0.005,0.005,0.01,0.0125/
     DATA CL21/-0.1,-0.075,0.0,0.1,0.2,0.3,0.4,0.433,0.467,0.483,
    05,0.508,0.517,0.533,0.6,0.7/
     DATA CM21/-.0625,-.035,-.03,-.0225,-.015,-.01,0.0,0.0,0.0,0.015,
    0025,0.0575,0.07,0.0725,0.065,0.0525/
     CM330=CMTHKF(M,TC,CLF,T,6,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
    &CM6,CM9,CM12,CM15,CM21,CM30,11,15,13,15,19,16,0)
     RETURN
     END
C
C
C
     FUNCTION CM345(M,TC,CLF)
     DIMENSION T(6),CL2(11),CM2(11),CL6(12),CM6(12),CL9(15),CM9(15),
    &CL12(18),CM12(18),CL15(20),CM15(20),CL21(15),CM21(15)
     DIMENSION CL30(1),CM30(1)
     REAL M
     DATA T/0.02,0.06,0.09,0.12,0.15,0.21/
     DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
     DATA CM2/-.075,-.07,-.077,-.08625,-.08125,-.0755,-.0735,-.069,
    &-.05925,-.05625,-.07/
     DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.85,0.9/
     DATA CM6/-.075,-.07,-.07,-.0675,-.065,-.0625,-.06,-.0525,-.045,
    &-.04,-.036,-.04/
     DATA CL9/-0.1,0.0,0.05,0.1,0.2,0.25,0.3,0.4,0.475,0.5,0.6,0.7,
    08,0.85,0.9/
     DATA CM9/-.075,-.07,-.07,-.0675,-.06,-.055,-.056,-.055,-.0525,
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&-.05,-.04,-.034,-.0275,-.025,-.02/
 DATA CL12/-0.1,0.0,0.1,0.2,0.25,0.3,0.4,0.433,0.467,0.5,0.525,
055,0.575,0.6,0.7,0.8,0.883,0.9/
 DATA CM12/-.0825,-.08,-.0675,-.06,-.055,-.0525,-.05,-.0525,
&-.0475,-.04,-.034,-.0275,-.024,-.02,-.015,-.0125,-.01,-.0075/
 DATA CL15/0.0,0.05,0.1,0.125,0.15,0.2,0.3,0.4,0.45,0.475,0.5,
0525,0.55,0.567,0.583,0.6,0.7,0.783,0.8,0.9/
 DATA CM15/-.0775,-.065,-.055,-.05,-.0475,-.045,-.0425,-.0375,
&-.0325,-.03,-.0225,-.01,-.005,0.015,0.0175,0.0175,0.0175,0.02,
0022,0.0275/
 DATA CL21/-0.1,0.0,0.1,0.2,0.3,0.38,0.4,0.425,0.45,0.475,0.5,
0525,0.55,0.6,0.7/
 DATA CM21/-.0425,-.03,-.0225,-.0125,-.0025,0.005,0.01,0.025,0.05,
0065,0.075,0.08,0.0825,0.0825,0.0825/
 CM345=CMTHKF(M,TC,CLF,T,6,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,11,12,15,18,20,15,0)
 RETURN
 END
C
C
C
 FUNCTION CM360(M,TC,CLF)
 DIMENSION T(6),CL2(12),CM2(12),CL6(15),CM6(15),CL9(13),CM9(13),
&CL12(17),CM12(17),CL15(22),CM15(22),CL21(17),CM21(17)
 DIMENSION CL30(1),CM30(1)
 REAL M
 DATA T/0.02,0.06,0.09,0.12,0.15,0.21/
 DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/
 DATA CM2/-.082,-.077,-.0786,-.095,-.095,-.0875,-.0775,-.07375,
&-.0775,-.081,-.07,-.122/
 DATA CL6/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,0.94286,
097145,0.9857,1.0/
 DATA CM6/-.082,-.08036,-.0786,-.0768,-.075,-.0714,-.06786,
&-.0607,-.0536,-.0464,-.0375,-.0357,-.0393,-.04286,-.05/
 DATA CL9/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.7,0.8,0.9,1.0/
 DATA CM9/-.0893,-.0875,-.0786,-.0714,-.06786,-.0643,-.0607,
&-.0571,-.05,-.0339,-.0214,-.0143,-.0089/
 DATA CL12/-0.1,0.0,0.1,0.2,0.25,0.3,0.4,0.475,0.5,0.55,0.6,
065,0.7,0.75,0.8,0.875,0.9/
 DATA CM12/-.107,-.0982,-.0857,-.075,-.0714,-.06786,-.0643,
&-.0589,-.0536,-.04286,-.0286,-.01786,-.007,-.0036,0.0,0.00536,
0007/
 DATA CL15/-0.1,0.0,0.1,0.157,0.1786,0.2,0.2286,0.3,0.4,0.45,
05,0.5286,0.557,0.5857,0.6,0.6143,0.65,0.7,0.75,0.8,0.9,1.0/
 DATA CM15/-.15,-.1125,-.0786,-.0589,-.0536,-.05,-.0464,-.0464,
&-.0446,-.04286,-.0357,-.02857,-.01786,0.0,0.0143,0.025,0.032,
00357,0.0357,0.0357,0.0339,0.0286/
 DATA CL21/-0.1,0.0,0.1,0.2,0.3,0.4,0.4143,0.4357,0.457,0.4786,
05,0.55,0.6,0.6286,0.7,0.75,0.8/
 DATA CM21/-.04286,-.0286,-.0232,-.0143,0.0,0.01786,0.0286,
006786,0.0857,0.09286,0.1,0.107,0.1125,0.1143,0.1125,0.1089,
01/
 CM360=CMTHKF(M,TC,CLF,T,6,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,12,15,13,17,22,17,0)
 RETURN
 END
C
C
C
 FUNCTION CM370(M,TC,CLF)
 DIMENSION T(5),CL2(11),CM2(11),CL6(14),CM6(14),CL9(13),CM9(13),
&CL12(9),CM12(9),CL15(11),CM15(11)
 DIMENSION CL21(1),CL30(1),CM21(1),CM30(1)
 REAL M
 DATA T/0.02,0.06,0.09,0.12,0.15/
 DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
 DATA CM2/-.076,-.072,-.0875,-.098,-.095,-.094,-.093,-.086,-.087,
&-.097,-.0997/
 DATA CL6/-0.2,-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.65,0.7,0.8,
085,0.9/
 DATA CM6/-.08958,-.08958,-.0875,-.0875,-.0854,-.0854,-.0833,
&-.0833,-.08125,-.08125,-.0792,-.075,-.0729,-.0667/
 DATA CL9/-0.2,-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.75,0.8,0.9/
 DATA CM9/-.1083,-.1042,-.1,-.0875,-.0792,-.0771,-.075,-.075,
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     &-.075,-.0667,-.06458,-.0583,-.0417/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM12/-.1333,-.11458,-.0958,-.08125,-.0667,-.0625,-.0583,
     &-.0521,-.0417/
      DATA CL15/0.0,0.1,0.133,0.167,0.2,0.3,0.4,0.5,0.55,0.6,0.7/
      DATA CM15/-.15,-.08125,-.0625,-.05,-.0458,-.0417,-.0417,
     &-.0458,-.0479,-.0479,-.05/
      CM370=CMTHKF(M,TC,CLF,T,5,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,11,14,13,9,11,0,0)
      RETURN
      END
C
C
C
      FUNCTION CM375(M,TC,CLF)
      DIMENSION T(3),CL2(8),CM2(8),CL6(11),CM6(11),CL9(10),CM9(10)
      DIMENSION CL12(1),CL15(1),CL21(1),CL30(1),CM12(1),CM15(1),
     &CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09/
      DATA CL2/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6/
      DATA CM2/-.129,-.1333,-.11,-.1,-.1057,-.1062,-.09935,-.1002/
      DATA CL6/-0.3,-0.2,-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM6/-.1083,-.1083,-.1083,-.10625,-.1042,-.1,-.1,-.0979,
     &-.09375,-.0917,-.09375/
      DATA CL9/-0.3,-0.2,-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6/
      DATA CM9/-.1083,-.1083,-.1042,-.1,-.1,-.1,-.0958,-.0917,
     &-.08958,-.0854/
      CM375=CMTHKF(M,TC,CLF,T,3,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,8,11,10,0,0,0,0)
      RETURN
      END
C
C
C
      FUNCTION CM5FF(M,TC,CLF)
      DIMENSION A(5),X(3),Y(3)
      REAL M
      DATA A/0.3,0.45,0.6,0.7,0.75/
      N=2
      IS=1
      IL=IS+N-1
      IF(M.LE.A(IL)) GO TO 2
      IL=2
      IS=IL-N+1
      IF(M.GE.A(IS)) GO TO 2
      IS=1
      IL=IS+N-1
    3 IF((M-A(IS))*(M-A(IL)).LE.0.0) GO TO 2
      IS=IL
      IL=IS+N-1
      GO TO 3
    2 DO 4 I=IS,IL
      J=I-IS+1
      X(J)=A(I)
      GO TO (30,45,60,70,75),I
   30 Y(J)=CM530(M,TC,CLF)
      GO TO 4
   45 Y(J)=CM545(M,TC,CLF)
      GO TO 4
   60 Y(J)=CM560(M,TC,CLF)
      GO TO 4
   70 Y(J)=CM570(M,TC,CLF)
      GO TO 4
   75 Y(J)=CM575(M,TC,CLF)
    4 CONTINUE
      CM5FF=YLAGN(X,Y,N,M)
      RETURN
      END
C
C
C
      FUNCTION CM530(M,TC,CLF)
      DIMENSION T(7),CL2(11),CM2(11),CL6(16),CM6(16),CL9(14),CM9(14),
```

```
&CL12(18),CM12(18),CL15(15),CM15(15),CL21(14),CM21(14),CL30(11),
&CM30(11)
 REAL M
 DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
 DATA CL2/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/
 DATA CM2/-.106,-.10625,-.1135,-.1135,-.1135,-.1135,-.136,
&-.1495,-.09,-.0715,-.061/
 DATA CL6/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.625,0.65,0.675,0.7,0.725,
075,0.8,0.9,1.0/
 DATA CM6/-.10625,-.10625,-.1042,-.1042,-.10625,-.10625,-.10625,
&-.10625,-.1021,-.1,-.0917,-.0833,-.0771,-.075,-.0667,-.0625/
 DATA CL9/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.625,0.675,0.7,0.725,0.8,
09,1.0/
 DATA CM9/-.1083,-.10625,-.1021,-.1,-.1,-.1,-.09375,-.0917,
&-.0792,-.0708,-.0667,-.0625,-.0583,-.0542/
 DATA CL12/0.0,0.1,0.2,0.3,0.35,0.4,0.5,0.575,0.6,0.625,0.65,
0675,0.7,0.75,0.8,0.9,0.95,1.0/
 DATA CM12/-.1125,-.1083,-.1042,-.0979,-.09375,-.0917,-.0917,
&-.0896,-.0875,-.0854,-.0833,-.075,-.0708,-.05,-.0458,-.0417,
&-.0375,-.03125/
 DATA CL15/0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.7,0.75,0.8,
085,0.9,1.0/
 DATA CM15/-.1167,-.1021,-.0896,-.0833,-.0792,-.0729,-.0667,
&-.0604,-.0542,-.0396,-.0292,-.0208,-.0167,-.0146,-.0146/
 DATA CL21/0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.683,0.7,
0717,0.75,0.8/
 DATA CM21/-.0575,-.055,-.05,-.0475,-.0425,-.04,-.035,-.0275,
&-.0125,0.0075,0.015,0.0225,0.0275,0.03/
 DATA CL30/-0.1,-0.05,0.0,0.1,0.2,0.3,0.35,0.4,0.45,0.475,0.5/
 DATA CM30/0.0,0.00625,0.0104,0.0167,0.025,0.0333,0.0375,0.0417,
00521,0.0583,0.0667/
 CM530=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,11,16,14,18,15,14,11)
 RETURN
 END
C
C
C
 FUNCTION CM545(M,TC,CLF)
 DIMENSION T(7),CL2(11),CM2(11),CL6(15),CM6(15),CL9(14),CM9(14),
&CL12(14),CM12(14),CL15(17),CM15(17),CL21(13),CM21(13),CL30(9),
&CM30(9)
 REAL M
 DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
 DATA CL2/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/
 DATA CM2/-.1167,-.1146,-.1125,-.116,-.124,-.117,-.13,-.128,
&-.104,-.092,-.084/
 DATA CL6/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.6333,0.675,0.7,0.75,
0775,0.8,0.9,1.0/
 DATA CM6/-.1167,-.1146,-.1146,-.1125,-.1125,-.1125,-.1125,
&-.1104,-.1083,-.1,-.0896,-.0833,-.0792,-.075,-.0667/
 DATA CL9/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.625,0.675,0.7,0.75,
08,0.9,1.0/
 DATA CM9/-.1167,-.1146,-.1146,-.1083,-.10625,-.1042,-.1,-.1,
&-.0875,-.08125,-.0667,-.0604,-.0583,-.0521/
 DATA CL12/0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.7,0.75,0.8,
085,0.9/
 DATA CM12/-.1167,-.1125,-.1083,-.1021,-.1,-.0958,-.0917,-.0875,
&-.0792,-.06875,-.0542,-.0417,-.0333,-.0333/
 DATA CL15/0.0,0.1,0.2,0.25,0.3,0.4,0.5,0.6,0.625,0.65,0.675,
07,0.725,0.8,0.9,0.95,1.0/
 DATA CM15/-.125,-.1146,-.1,-.0917,-.0854,-.08125,-.075,-.06875,
&-.0667,-.0583,-.05,-.0333,-.025,-.0167,-.00625,0.0,0.0/
 DATA CL21/0.1,0.133,0.2,0.3,0.4,0.5,0.55,0.6,0.625,0.65,0.675,
07,0.8/
 DATA CM21/-.06,-.05,-.0475,-.0425,-.04,-.0325,-.0225,-.01,0.0,
001,0.025,0.0325,0.0375/
 DATA CL30/-0.1,-0.075,-0.05,0.0,0.1,0.2,0.3,0.35,0.4/
 DATA CM30/0.0083,0.0146,0.01875,0.025,0.0271,0.0458,0.05083,
005125,0.075/
 CM545=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
&CM6,CM9,CM12,CM15,CM21,CM30,11,15,14,14,17,13,9)
 RETURN
 END
```

```
C
C
C
      FUNCTION CM560(M,TC,CLF)
      DIMENSION T(7),CL2(10),CM2(10),CL6(14),CM6(14),CL9(18),CM9(18),
     &CL12(17),CM12(17),CL15(19),CM15(19),CL21(13),CM21(13),CL30(11),
     &CM30(11)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15,0.21,0.30/
      DATA CL2/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9/
      DATA CM2/-.1065,-.126,-.116,-.129,-.132,-.13,-.114,-.1245,
     &-.1765,-.084/
      DATA CL6/-0.1,-0.05,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.75,0.8,
     0825,0.85/
      DATA CM6/-.1229,-.1271,-.1292,-.13125,-.13125,-.1292,-.1292,
     &-.1271,-.125,-.1229,-.1167,-.1083,-.1021,-.0958/
      DATA CL9/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.65,0.675,0.7,0.725,0.75,
     0775,0.8,0.825,0.85,0.875,0.9/
      DATA CM9/-.1375,-.1333,-.13125,-.1292,-.1229,-.1208,-.1229,
     &-.1229,-.1208,-.1167,-.10625,-.0917,-.0792,-.0708,-.0625,
     &-.05625,-.0521,-.05/
      DATA CL12/0.0,0.1,0.2,0.275,0.3,0.35,0.4,0.433,0.5,0.55,0.6,
     0675,0.7,0.75,0.775,0.8,0.85/
      DATA CM12/-.1375,-.1333,-.125,-.1208,-.1167,-.1125,-.1104,
     &-.1083,-.10625,-.10417,-.1021,-.1,-.0979,-.0833,-.0708,-.0583,
     &-.0417/
      DATA CL15/0.0,0.1,0.2,0.225,0.25,0.3,0.325,0.4,0.5,0.6,0.65,
     0675,0.7,0.725,0.75,0.775,0.8,0.85,0.9/
      DATA CM15/-.15,-.1375,-.125,-.1208,-.1125,-.0917,-.0875,-.0833,
     &-.0792,-.075,-.0708,-.06875,-.06458,-.0542,-.0417,-.025,
     &-.01875,-.0125,-.0083/
      DATA CL21/0.1,0.2,0.3,0.4,0.45,0.5,0.55,0.6,0.625,0.65,0.7,0.8,
     09/
      DATA CM21/-.0542,-.05,-.0417,-.0354,-.0333,-.025,-.01458,
     00042,0.01458,0.0208,0.0271,0.0354,0.0417/
      DATA CL30/-0.3,-0.2,-0.1,0.0,0.05,0.1,0.125,0.2,0.25,0.3,0.4/
      DATA CM30/0.0333,0.04375,0.0542,0.0625,0.06875,0.0833,0.0875,
     01,0.1,0.1,0.1021/
      CM560=CMTHKF(M,TC,CLF,T,7,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,10,14,18,17,19,13,11)
      RETURN
      END
C
C
C
      FUNCTION CM570(M,TC,CLF)
      DIMENSION T(6),CL2(9),CM2(9),CL6(7),CM6(7),CL9(9),CM9(9),CL12(9),
     &CM12(9),CL15(14),CM15(14),CL21(11),CM21(11)
      DIMENSION CL30(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15,0.21/
      DATA CL2/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM2/-.2175,-.2,-.101,-.11,-.1415,-.14,-.145,-.146,-.144/
      DATA CL6/0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM6/-.1479,-.1458,-.1458,-.1458,-.1417,-.1417,-.1375/
      DATA CL9/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM9/-.1583,-.1542,-.1521,-.1458,-.14375,-.1417,-.1354,
     &-.1333,-.1292/
      DATA CL12/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8/
      DATA CM12/-.1542,-.145,-.14,-.1275,-.1175,-.1175,-.1175,
     &-.1175,-.115/
      DATA CL15/0.0,0.1,0.15,0.175,0.2,0.225,0.25,0.275,0.2917,0.3,
     04,0.5,0.6,0.7/
      DATA CM15/-.17,-.16,-.155,-.1525,-.15,-.145,-.13,-.11,-.1,-.09,
     &-.085,-.0775,-.0725,-.065/
      DATA CL21/-0.2,-0.1,0.0,0.025,0.05,0.075,0.1,0.125,0.175,0.2,0.3/
      DATA CM21/-.04,-.0325,-.025,-.02,-.0175,-.01,0.0,0.01,0.0225,
     0025,0.0375/
      CM570=CMTHKF(M,TC,CLF,T,6,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,9,7,9,9,14,11,0)
      RETURN
      END
C
C
```

```
C
      FUNCTION CM575(M,TC,CLF)
      DIMENSION T(5),CL2(8),CM2(8),CL6(8),CM6(8),CL9(10),CM9(10),
     &CL12(9),CM12(9),CL15(8),CM15(8)
      DIMENSION CL21(1),CL30(1),CM21(1),CM30(1)
      REAL M
      DATA T/0.02,0.06,0.09,0.12,0.15/
      DATA CL2/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM2/0.318,0.24625,-.4565,-.4625,-.633,-.633,-.633,-.524/
      DATA CL6/0.2,0.3,0.4,0.5,0.6,0.65,0.7,0.8/
      DATA CM6/-.1575,-.1575,-.16,-.16,-.16,-.1625,-.165,-.1725/
      DATA CL9/0.0,0.1,0.2,0.3,0.4,0.5,0.55,0.6,0.65,0.7/
      DATA CM9/-.0708,-.0708,-.0667,-.0646,-.0625,-.0625,-.0604,
     &-.0583,-.0521,-.0458/
      DATA CL12/-0.1,0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7/
      DATA CM12/-.16,-.1525,-.145,-.135,-.125,-.115,-.105,-.1,-.085/
      DATA CL15/-0.05,0.0,0.1,0.2,0.3,0.35,0.4,0.5/
      DATA CM15/-.09375,-.08958,-.075,-.0625,-.0479,-.0417,-.0375,
     &-.0333/
      CM575=CMTHKF(M,TC,CLF,T,5,CL2,CL6,CL9,CL12,CL15,CL21,CL30,CM2,
     &CM6,CM9,CM12,CM15,CM21,CM30,8,8,10,9,8,0,0)
      RETURN
      END
C
C
C
      FUNCTION CMTHKF(M,TC,CLF,T,NA,CL1,CL2,CL3,CL4,CL5,CL6,CL7,CM1,
     &CM2,CM3,CM4,CM5,CM6,CM7,N1,N2,N3,N4,N5,N6,N7)
      DIMENSION T(1),CL1(1),CL2(1),CL3(1),CL4(1),CL5(1),CL6(1),CL7(1),
     &CM1(1),CM2(1),CM3(1),CM4(1),CM5(1),CM6(1),CM7(1)
      DIMENSION X(2),Y(2)
      REAL M
      TCR=TC
      IF(TCR.LE.T(1)) TCR=T(1)
      N=2
      CALL OUT(NA,N,IS,IL,T,TCR)
      DO 30 I=IS,IL
      X(I-IS+1)=T(I)
      GO TO (1,2,3,4,5,6,7),I
    1 ANS=GETF(N1,N,CL1,CM1,M,TC,CLF)
      GO TO 20
    2 ANS=GETF(N2,N,CL2,CM2,M,TC,CLF)
      GO TO 20
    3 ANS=GETF(N3,N,CL3,CM3,M,TC,CLF)
      GO TO 20
    4 ANS=GETF(N4,N,CL4,CM4,M,TC,CLF)
      GO TO 20
    5 ANS=GETF(N5,N,CL5,CM5,M,TC,CLF)
      GO TO 20
    6 ANS=GETF(N6,N,CL6,CM6,M,TC,CLF)
      GO TO 20
    7 ANS=GETF(N7,N,CL7,CM7,M,TC,CLF)
   20 Y(I-IS+1)=ANS
   30 CONTINUE
      CMTHKF=YLAGN(X,Y,N,TCR)
      RETURN
      END
C
C
C
      FUNCTION GETF(NMAX,N,XCL,YCM,M,TC,CLF)
      DIMENSION XCL(1),YCM(1),U(3),V(3)
      REAL M
      IF(CLF.GT.XCL(1)) GO TO 1
      GETF=YCM(1)
      RETURN
    1 CALL OUT(NMAX,N,JS,JL,XCL,CLF)
      DO 2 J=JS,JL
      U(J-JS+1)=XCL(J)
      V(J-JS+1)=YCM(J)
    2 CONTINUE
      GETF=YLAGN(U,V,N,CLF)
      RETURN
      END
```

```
C
      SUBROUTINE OUT(NMAX,N,IS,IL,Y,X)
      DIMENSION Y(1)
      IS=1
      IL=IS+N-1
      IF(X.LE.Y(IL)) RETURN
      IL=NMAX
      IS=IL-N+1
      IF(X.GE.Y(IS)) RETURN
      IS=1
    1 IL=IS+N-1
      IF((X-Y(IS))*(X-Y(IL)).LE.0.0) RETURN
      IS=IL
      GO TO 1
      END
C
C
C
      FUNCTION YLAGN(X,Y,N,Z)
C
C PERFORMS THE LAGRANGE INTERPOLATION
C
      DIMENSION X(1),Y(1)
      SUM=0.0
      DO 1 I=1,N
      S=1.0
      DO 2 J=1,N
      IF(J.EQ.I) GO TO 2
      S=S*(Z-X(J))/(X(I)-X(J))
    2 CONTINUE
      SUM=SUM+S*Y(I)
    1 CONTINUE
      YLAGN=SUM
      RETURN
      END
C
C---------------------------------------------------------------------
C
C     END OF DATA INFORMATION
C
C*********************************************************************
C
C
C
      SUBROUTINE ATMCON(ALTUDE,TEMP,PRES,DEN,VIS,WA)
C
      ALTUDE=ALTUDE*.3048
      SLOPE=-.0065
      TEMP=288.16+SLOPE*ALTUDE
      EXP=2.718281828
      TSEA=288.16
      PSEA=101325.
      PRES1=22700.
      GRAV=9.82
      R=288.
      POWER=GRAV/(SLOPE*R)
      PRES=PSEA*(1/(TEMP/TSEA))**POWER
      IF(ALTUDE.LE.11000.) GO TO 1
      PRES=PRES1*EXP**(-GRAV/(R*216.66)*(ALTUDE-11000.))
      TEMP=216.66
    1 WA=SQRT(1.4*R*TEMP)/.3048
      TEMP=(TEMP-273.15)*9/5+491.67
      VIS=.35*(TEMP/492.)**1.5*(690/(TEMP+198.))*.000001
      PRES=PRES*2116.2/PSEA
      DEN=PRES/(1718.*TEMP)
      ALTUDE=ALTUDE/.3048
      RETURN
      END
C
C
C
      SUBROUTINE TEST(TC,MXMACH)
C
C
```

```
      INTEGER THL
      REAL MMACH(4)
      REAL MXMACH
C
C
      DATA MMACH/0.845,0.770,0.700,0.625/
C
    3 S=0.7143
C
C
      THL=INT(TC*10)
C
      DELTHI= TC-(THL/10.)
      THL=THL+1
C
      MXMACH=MMACH(THL)-DELTHI*S
C
      RETURN
      END
C
      SUBROUTINE AOAT(M,ALTEST,K)
C
C
      REAL M
      DIMENSION ALL(5)
      DATA ALL/18.667,14.5,10.4,6.2,2.03/
C
      S=-41.667
      IF(M.GE.1.0) RETURN
      MM=INT(M*10.)-4
      DEL=M-(INT(M*10.)/10.)
      ALTEST=ALL(MM)+DEL*S
C
      RETURN
      END
C
      SUBROUTINE N16COR(L,CHORD,TC,CLD,AREA)
      DIMENSION X(14),YU(14),YL(14),C1(12),C2(12),C3(12),C4(12)
      DATA C1/.0093,.0158,.02587,.03982,.04861,.05356,.05516,.05356,
     &.04861,.03982,.02587,.0158/
      DATA C2/.1272,.09653,.066,.03473,.01461,.00394,0.0,.00447,.01895,
     &.044,.05961,.05469/
      DATA C3/.15044,.20911,.28811,.38867,.45144,.48789,.5,.48622,
     &.43911,.34989,.20978,.11789/
      DATA C4/.00639,.00574,.0044,.00237,.00103,.00025,0.0,.00025,.001,
     &.00213,.00321,.00324/
      REAL LERAD,IXC,IYC,MY,MX
      IF(L.EQ.0) RETURN
      THICK=TC
C
      LERAD=.489*THICK**2/CHORD
      TERAD=.01*THICK
      SLOPE=.62234*CLD
      AREA=.7396*(1+.00544*CLD**2)*THICK*CHORD
      MY=.3569*(1+.00458*CLD**2)*THICK*CHORD**2
      MX=.03335*(1+.00196*CLD**2)*CLD*THICK*CHORD**2+.01775*(1+.1332*CLD
     *2)*CLD*THICK**3
      IYC=.04221*(1+.01287*CLD**2)*THICK*CHORD**3
      IXC=.04476*(1-.00182*CLD**2)*THICK**3*CHORD+.00009358*(1+.02013*CL
     &D**2)*CLD**2*THICK*CHORD**3
      THETA=ATAN(SLOPE)
      DY1=LERAD*SIN(THETA)
      X(1)=0.0
      YU(1)=DY1
      YL(1)=DY1
      X(2)=.025*CHORD
      X(3)=2*X(2)
      DO 1 I=1,9
    1 X(I+3)=FLOAT(I)/10*CHORD
      X(13)=.95*CHORD
      X(14)=CHORD
      DO 2 I=1,12
      COM1=C1(I)*CLD*CHORD+C2(I)*CLD*THICK**2/CHORD
      COM2=C3(I)*THICK+C4(I)*CLD**2*THICK
```

```
      YU(I+1)=2*COM1
    2 YL(I+1)=COM1-COM2
      DY2=TERAD*SIN(THETA)
      YU(14)=DY2
      YL(14)=0.0
      NUMPTS=14
      WRITE(6,500)
  500 FORMAT('1',45X,'*** NACA-16 AIRFOIL DIMENSIONS ***',//' ',
     &39X,'X-COORDINATES',5X,'Y-COOR UPPER',6X,'Y-COOR LOWER'/)
      DO 3 I=1,NUMPTS
      X(I)=X(I)/CHORD
      YU(I)=YU(I)/CHORD
      YL(I)=YL(I)/CHORD
      IF(CLD.NE.0.0) GO TO 3
      YU(I)=-YL(I)
    3 WRITE(6,600) X(I),YU(I),YL(I)
  600 FORMAT(' ',39X,F10.6,8X,F10.6,8X,F10.6)
      WRITE(6,700) THICK,CHORD,AREA
  700 FORMAT(' ',5(/),40X,'(T/C)MAX',7X,'CHORD(FT)',8X,'AREA(FT**2)',
     &/38X,F10.6,6X,F10.6,7X,F10.6)
      WRITE(6,800) IXC,IYC
  800 FORMAT(' ',5(/),50X,'MAJOR',12X,'MINOR',/50X,'MOMENT',11X,
     &'MOMENT',/49X,'INERTIA',10X,'INERTIA',/46X,F10.5,7X,F10.5)
      RETURN
      END
//$DATA
//$STOP
```

Appendix II

NACA 16-Series Program Case

Input/Output

```
      REAL M(3)
      DATA M/0.3,0.5,0.7/
      DATA ANGLE/0.0,2.0,4.0/
      DATA ALTUDE/0./
      DATA CHORD/1.000/
      DATA TC/0.15/
      DATA CLD/0.2/
      DATA ICL/1/
      DATA ICD/1/
      DATA X/.50/
      DATA NUMACH/3/
      DATA NUMALP/3/
      DATA IFORM/1/
      DATA MP/1/
      DATA L/1/
```

*** NACA-16 AIRFOIL DIMENSIONS ***

X-COORDINATES	Y-COOR UPPER	Y-COOR LOWER
0.000000	0.000110	0.000110
0.025000	0.004336	-0.003863
0.050000	0.007280	-0.004736
0.100000	0.011853	-0.005607
0.200000	0.018195	-0.006454
0.300000	0.022191	-0.006964
0.400000	0.024442	-0.007295
0.500000	0.025170	-0.007415
0.600000	0.024443	-0.007228
0.700000	0.022195	-0.006469
0.800000	0.018202	-0.004899
0.900000	0.011848	-0.002474
0.950000	0.007249	-0.001098
1.000000	0.000056	0.000000

(T/C)MAX	CHORD(FT)	AREA(FT**2)
0.040000	1.000000	0.029592

MAJOR MOMENT INERTIA	MINOR MOMENT INERTIA
0.00000	0.00169

*** LIMITATIONS ***

* NACA 16,6 SERIES AIRFOIL DATA BANK *

ALTITUDE = 0.0000 FEET

CHORD = 1.000000 FEET

(T/C)MAX = 0.040000

CLD = 0.228150

ALPHALO = -2.000000 DEG.

MACH NO. = 0.450000

REYNOLDS NO. = 0.327645E 01

ALPHA	CL	CD	CL/CD	CM(LED)
0.000000	0.241398	0.005540	43.573160	-0.090616
2.000000	0.482795	0.008086	59.703960	-0.149024
4.000000	0.724193	0.020606	35.145470	-0.206057

* NACA 16,6 SERIES AIRFOIL DATA BANK *

ALTITUDE = 0.0000 FEET

CHORD = 1.000000 FEET

(T/C)MAX = 0.040000

CLD = 0.228150

ALPHALO = -2.000000 DEG.

MACH NO. = 0.700000

REYNOLDS NO. = 0.509669E 01

ALPHA	CL	CD	CL/CD	CM(LED)
0.000000	0.312860	0.005867	53.323080	-0.112138
2.000000	0.625720	0.011710	53.436300	-0.182580
4.000000	0.938580	0.044125	21.270780	-0.173298

* NACA 16,6 SERIES AIRFOIL DATA BANK *

ALTITUDE = 0.0000 FEET

CHORD = 1.000000 FEET

(T/C)MAX = 0.040000

CLD = 0.228150

ALPHALO = -2.000000

MACH NO. = 0.700000

REYNOLDS NO. = 5.096695

ALPHA	CL	CD	CL/CD	CM(LED)
0.000000	0.312860	0.005867	53.323080	-0.112138
2.000000	0.625720	0.011710	53.436300	-0.182580
4.000000	0.938580	0.044125	21.270780	-0.173298